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THE INHERITANCE OF PRODUCTIVITY IN FARM LIVE STOCK[1]

I. MEAT.

JOHN HAMMOND

(*School of Agriculture, Cambridge*)

With Plates 1–6

Introduction.—Almost all the characters that are of any importance for meat (such as weight-for-age and body-proportions) in our farm animals are dependent for their full expression on environment and nutrition. We cannot therefore consider the genetic characters for meat-production without considering the environment in which they are developed. In my opinion, most of these characters have been developed purposely, and their development has been planned and directed by man through selection in an environment that he has created to produce them, whilst in only a very small minority of cases have they arisen by chance from large mutations. The large mutations that occur in our live stock are nearly all of the recessive type, and for the most part consist of defects and abnormalities or fancy points (such as colour and horns), which are of little commercial importance. They usually segregate out in simple ratios, and it is an easy matter to breed for them by using Mendelian methods. On the other hand, almost all the commercial qualities are 'blending' in inheritance: there is no dominance, and in my opinion they have been produced by quite a different method, that is, by the accumulation of small variations, which are continually appearing, and may be stimulated by the environment. In my opinion, too, these characters exist in all degrees of 'fixity' in the animal. In other words, in terms of present-day explanations, I believe not only in the mutation of a gene already formed, but also in the possibility of the evolution of a new gene by the animal itself under the stimulation of the environment, and consequently of varying degrees of 'fixity' of characters under environmental change, according to the state of evolution of the gene in question. Whilst the animal produces the gene as a mechanism for putting the characters that it has evolved into its inheritance, a mutation in the gene already fully formed gives a variation in the animal that is of small importance in evolution, because it is at random and not purposeful, as in the former case. Thus I see the real evolution of commercial qualities, built up by small variations, constantly being added to according to the environment of the animal, and the formation of varieties, freaks, and fancy points produced by the mutation of genes already formed by the other process.

To illustrate the theories outlined above, I propose, in the short space available, to give a few examples. A concrete example may be given from the horse, which although not among the meat-producing animals in Great Britain is closely related to them. The evolution

[1] The five papers under this head were read to Section D (Zoology) of the British Association for the Advancement of Science, Aberdeen, September 10, 1934.

in the skeleton (Fig. 1, Plate 1) has followed a definite and uniform course of changes, consisting in the main of a progressive lengthening of the limb bones in relation to cranium size. This evolution has not been broken by a number of sharp changes, such as mutations affecting different parts of the body independently; for example, no shortened limb bones, such as those which occur in the Dachshund dog (and also occasionally in the horse) and behave as Mendelian recessives, come in the series. These things are mutations that may easily be picked out by man and bred to form fancy strains, but they play no real part either in natural evolution or in the development of the proportions of the body in commercial meat-production. These mutations do not as a rule form intermediates when bred to the normal type, whereas when two different 'developed' types are crossed, all gradations between them may be obtained. In the horse (see Fig. 1) the different types of conformation are magnifications (light horses) or extensions (heavy horses) of the gradual changes which have taken place during the course of evolution.

Cattle (*beef and veal*).—Beef qualities, i.e. a high proportion of the best joints (loin) and a low proportion of the offal parts (head and legs), are developmental characters, and change in their proportions as the animal grows up (Fig. 2, Pl. 2). The head and legs are proportionally large in the calf, and as the beef qualities develop they become proportionally smaller, and the loin becomes proportionally larger. For the full expression of these developmental characters, a high plane of nutrition is necessary, for, if it is not available, the later maturing and more valuable parts are not developed and the form of the animal approaches that of the unimproved type in which the head and legs are large and the loin poorly developed (see Fig. 2). If selection is made under poor conditions of nutrition, therefore, we cannot distinguish so well between the one which is poor in conformation due to lack of genetic improvement, and the one which is genetically improved but fails to develop its body proportions because of lack of nutrition. All the best breeds of beef cattle (Aberdeen-Angus, Shorthorn, Hereford) have been developed in areas of good nutrition, and herds in poor nutrition (range) areas become degenerate from a meat point of view, unless they are kept constantly supplied with breeding-stock which has been selected in the areas of high nutrition.

When we consider the different breeds of cattle from the standpoint of the development of body proportions for meat (Fig. 3, Pl. 3), it will be seen that they can be put in a series, according to the rate and extent to which these proportions are developed. A beef Shorthorn bull 14 months old is as well developed in its proportions for meat as an adult Friesian bull $5\frac{1}{2}$ years old, and the extent to which it develops eventually is far in excess of anything found in the dairy breeds. The directive influence of man's selection is seen in the way in which stocks having a different origin—such as the Aberdeen-Angus and the Shorthorn—approach one another in conformation for beef purposes (and Friesians and Dairy Shorthorns for milk purposes), whilst stocks with a common origin—such as the Shorthorn—have developed different types when bred for different purposes, such as beef and milk (see Fig. 3).

Of quite another nature genetically, and in no way dependent on environmental and nutritional conditions, is the 'Doppellender' calf, which is so much valued for veal on the Continent (Fig. 4, Pl. 4). It consists of a doubling of the muscles of the loin and hind quarters, and has arisen as a mutation in several Continental breeds of cattle, in which it is carried on in the heterozygous condition, for the females are sterile. It is a simple recessive and forms no blend in crossing as do the developmental characters. It cannot therefore be used to improve other stocks in the same way that Aberdeen-Angus bulls are used to introduce an improved conformation and better quality when mated to coarse-boned and ill-proportioned cows.

The colour of the body-fat in cattle is a multiple-factor genetic character; all shades of colour exist from a very pale yellow (which is desired by the butcher) to a deep yellow (which is desired by the breeder of dairy cattle). The expression of this character is dependent on the amount of the xanthophyll pigments of plants in the food, and if these are absent the fat becomes white, no matter what the genetic constitution is. In selecting for this character the breeders of dairy cattle feed plenty of greenstuff and pick out those cows which give the deepest yellow tint. Variability curves (by Whetham) for the colour of the butter-fat in the different breeds of cattle at the London Dairy Show are shown in the next figure (Fig. 5, p. 4). This is a case where a definite environment of food-supply is necessary before selection can be made for the genetic character concerned.

Sheep (*mutton and lamb*).—As with beef, the genetic characters for mutton and lamb are all 'developmental' ones, and in Great Britain there exists a complete range of types from those possessing early maturing qualities (that is, a quick change in the proportions of the body), and suitable for killing as lamb, to those with a slow change in proportions, which are more suited to mutton-production. These characters are not firmly fixed, however, and may be modified in any one breed by the methods of feeding and management adopted. During growth, the tissues of the body develop in a definite order—bone, muscle, and then fat. The proportional development of these tissues varies considerably in different breeds; this, for example, may be illustrated by the following average fat-measurements of the loins (Fig. 6, Pl. 4) of carcasses at Smithfield Show (Fig. 7—by Hirzel, p. 5). First crosses are intermediate between parents in this respect, and there is no dominance or recessiveness of such developmental characters.

On the other hand, an alteration of the proportions of the body brought about by a mutation (and not of a developmental character), such as that of the short legs of the Ancon sheep (Fig. 8, Pl. 5), behaves as a recessive segregating character, and does not blend with all gradations as do the developmental characters. The developmental characters must always be represented by a variability curve, and never as a fixed point, as the mutations can be. Improvement of the environment and selection of the animals at the upper end of the curve, for the curve shifts upwards as the result of environmental changes, are the best means of effecting improvements for early maturity.

Pigs (bacon, pork, and lard).—Local feed conditions have supplied the environment in which the different types of pigs have been evolved. For example, in the maize-producing areas of Hungary and Roumania, the

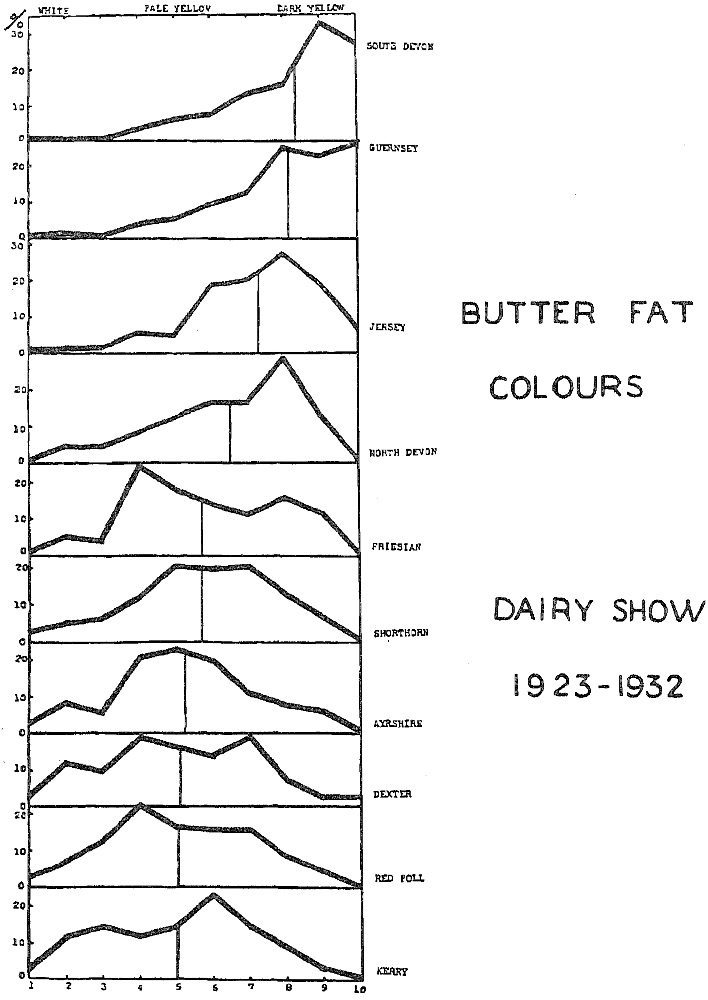

FIG. 5. (From Whetham—paper in preparation.)

Variability Curves of the Colour of Butter-fat in Different Breeds of Cattle—London Dairy Show data (1923–32). Range of colour measured on a butter-fat colour scale. 1=white, 10=dark yellow. The vertical lines show the mean values for the different breeds.

Mangalicza pig has been developed for fat-production; this pig has only a small development of bone and muscle, but the back fat, which it is bred for, reaches, in a good average pig of 390 lb. live-weight, a thickness of 5 in. at the shoulder and 4 in. at the loin. In the corn-belt of America, too, the Poland-China breed developed in the same way (Fig. 9, Pl. 5), but the type within the breed has been changed in recent years (owing to the

lack of demand for lard) by selection, and the much greater use of proteins in the ration. Under the feeding conditions existing in Denmark (skim milk and cereals), the bacon pig (in which a carcass of 150 lb., thick in lean, and with only a moderate amount of fat, is required) has reached its highest development. Progeny tests of growth and carcass quality, made under feeding conditions that stimulate the characters

THICKNESS OF FAT OVER LOIN (C) 9 MONTHS

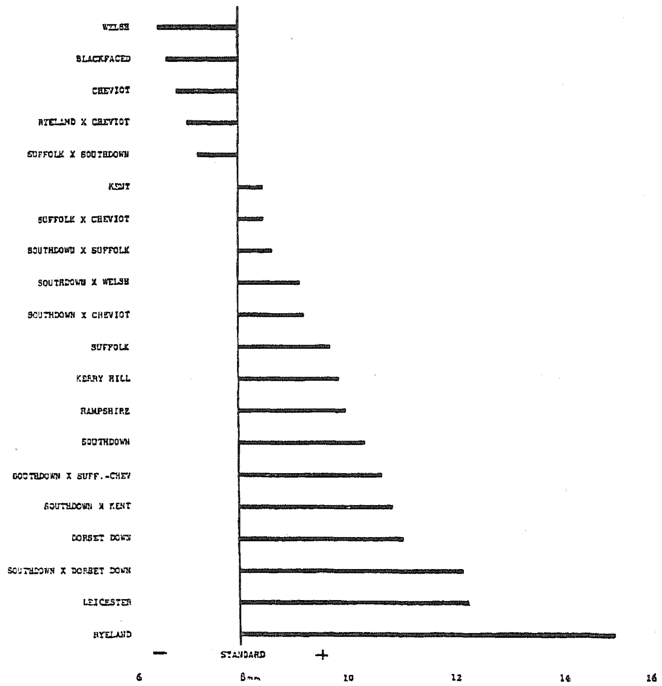

FIG. 7. (From Hirzel—paper in preparation.)

Measurements of Fat over the Loin in Different Breeds and Crosses of Sheep at Smithfield Show. For position of measurement see Fig. 6, Pl. 4. The measurements are shown as – or + the optimum measurement (8 mm.) desired by the public, and are breed averages over a number of years. Approximate age of carcasses—9 months.

required, are the means whereby this has been achieved. It has been a directed evolution of commercial qualities by the accumulation of small increases (as the progeny tests of their boars show), and not by the appearance of sudden large mutations. For pork (where a large development of the muscle at a low carcass weight—70 lb.—is required), it is in environments supplying a ration high in protein that the highest perfection is attained. New Zealand, for example, with its large supply of skim milk and meat meal is producing this type of pig to perfection from breeds as diverse as the Berkshire, Large White, and Tamworth (see Fig. 10, Pl. 6). The high-protein and low-carbohydrate feed leads to the development of the muscle and limits the fat to the proportions required

by the consumer, whereas under our conditions of high-carbohydrate feeding the differences in fatness between these breeds would be very marked. In general, the degree of fixity of the commercial character will depend on the order of its development in the animal; thus bone, which develops first, is more difficult to modify by local feeding conditions than is fat, which develops last. The developmental meat characters of the animal are genetically fixed only in relation to a certain environment. Conversely, if we wish to develop a certain character in our stock, we must carry out selection for that character in a suitable environment, if we are to be successful.

General conclusions.—Since the genetic characters concerned in meat-production are so dependent for their expression on the environment, especially nutrition (and are mostly of a developmental character), our best means of directive improvement is selection (by progeny tests) in a suitable environment, that is, one which stimulates the development of the character in question. The further development of these commercial qualities in our animals depends, like the 'civilization qualities' in man, on the creation of a better environment for the development of the characters concerned.

(*Received October 4, 1934*)

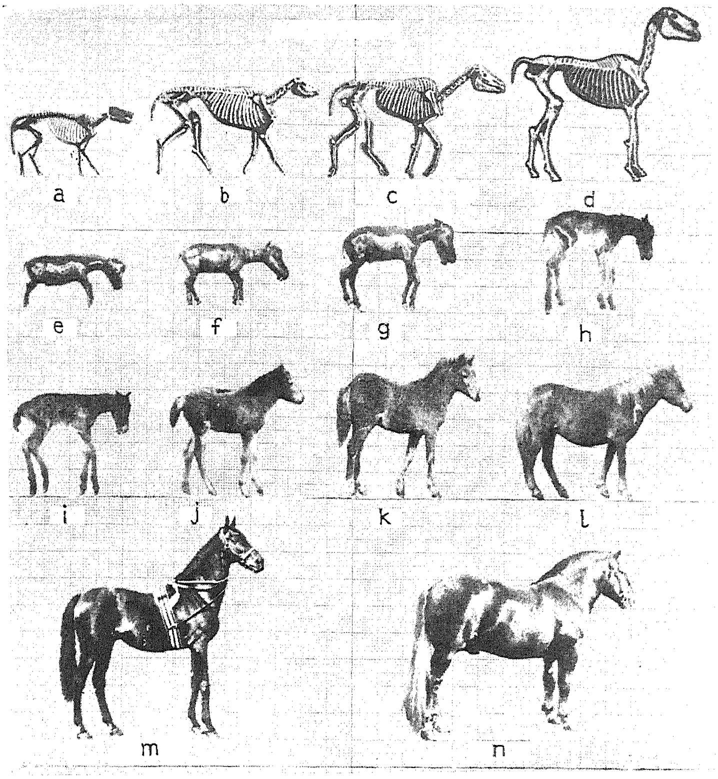

FIG. 1. THE CHANGES IN THE PROPORTIONS OF THE HORSE IN DEVELOPMENT AND DURING EVOLUTION

In order to show the changes in proportions, all the photographs have been reproduced to the same cranium size (eye to ear length). The changes in proportions during embryonic life parallel those which have taken place during evolution.

Reading from left to right:

Top line: EVOLUTION—(*a*) Eohippus; (*b*) Mesohippus; (*c*) Merychippus; (*d*) Equus (Arab).

Second line: DEVELOPMENT (Welsh Pony)—(*e*) 3 months; (*f*) 5 months; (*g*) 7 months; (*h*) 10 months.

Third line: DEVELOPMENT (Welsh Pony)—(*i*) 11 months; (*j*) 2 weeks after birth; (*k*) 9 weeks after birth; (*l*) adult.

Bottom line: EVOLUTION—(*m*) Light Horse (Thoroughbred—St. Simon); (*n*) Heavy Horse (Suffolk—Wedgwood).

(*From Hammond, 'Actes, 16^e Cong. Internat. d'Agric., Budapest,' 1934.*)

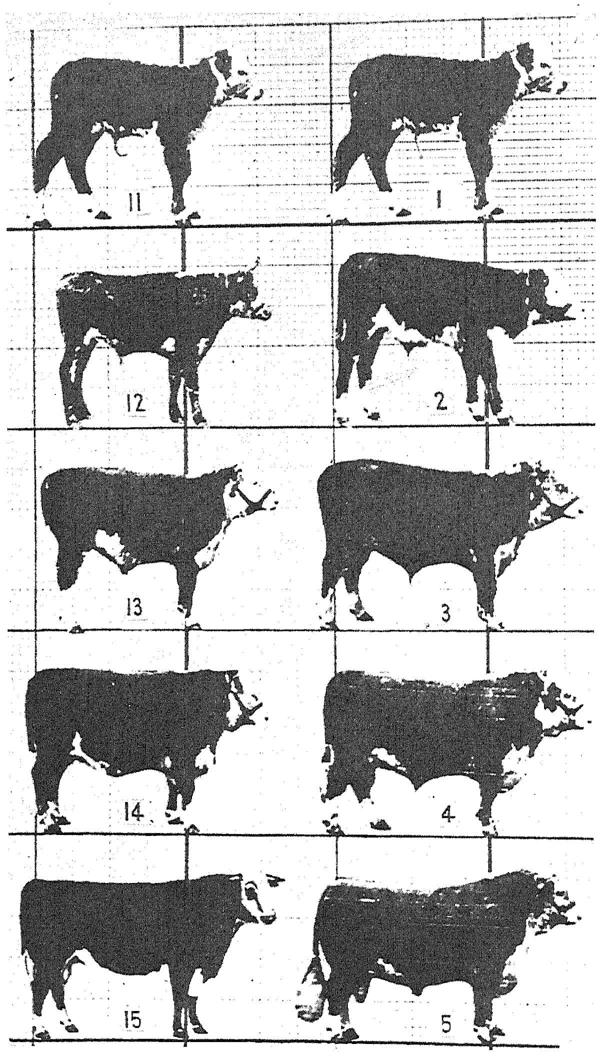

FIG. 2. CHANGES IN THE PROPORTIONS OF THE BODY IN HEREFORD CATTLE

In order to show changes in body proportions, as distinct from size, the photographs have all been reduced to the same height at the shoulders, so that the proportions are shown in relation to this measurement.

11. Heifer—2 days old.
12. Steer—30 months old (reared on low plane of nutrition).
13. Steer—11 months old (reared on high plane of nutrition).
14. Steer—22 months old (reared on high plane of nutrition).
15. Bull—adult—type existing 100 years ago.

1. Heifer—2 days old.
2. Bull—5 weeks old.
3. Bull—13 months old.
4. Bull—22 months old.
5. Bull—5 years old.

(*From Hammond, 'Actes, 14^e Cong. Internat. d'Agric., Bukarest,' 1929.*)

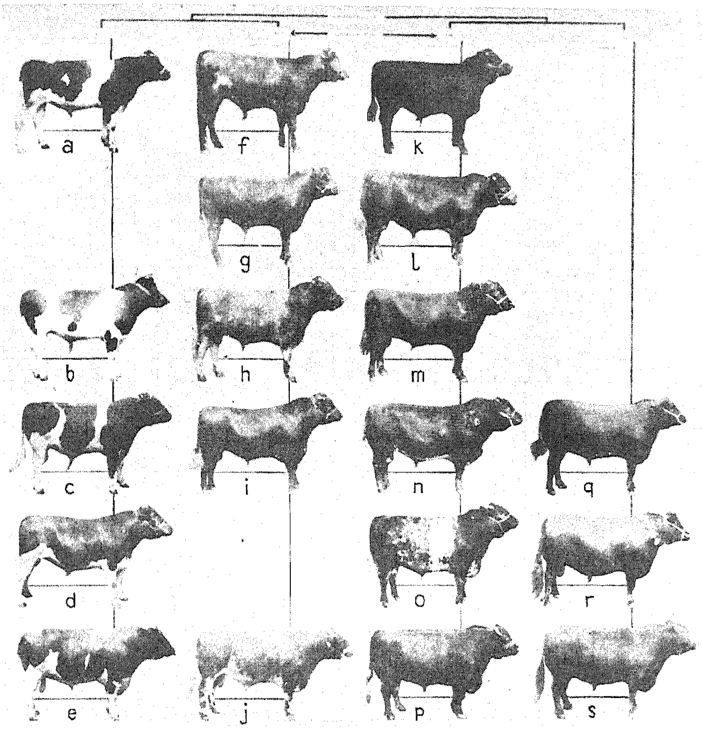

FIG. 3. PROPORTIONS AND AGE CHANGES IN BULLS OF DIFFERENT BREEDS

1st Prize Bulls at the Royal Agricultural Show, Manchester, 1930

Convergent Evolution

Divergent ←Evolution→

Milk *Friesian*	Milk *Dairy Shorthorn*	Beef *Beef Shorthorn*	Beef *Aberdeen Angus*
(*a*) 12 months	(*f*) 12 months	(*k*) 10 months	—
—	(*g*) 13 ,,	(*l*) 14 ,,	—
(*b*) 18 months	(*h*) 16 ,,	(*m*) 16 ,,	—
(*c*) 21 ,,	(*i*) 22 ,,	(*n*) 26 ,,	(*q*) 19 months
(*d*) 25 ,,	—	(*o*) 28 ,,	(*r*) 31 ,,
(*e*) 5½ years	(*j*) 4½ years	(*p*) 5½ years	(*s*) 5½ years

(*Photographs all reduced to the same shoulder-height.*)

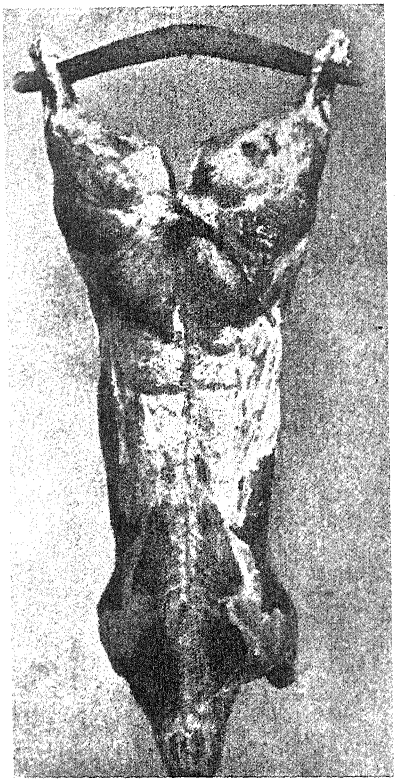

FIG. 4
CARCASS OF A 'DOPPELLENDER'
VEAL CALF

11 weeks old. Weight 367 lb.

(*From Herter and Wilsdorf, 'Arbeit deut. Landw.-Gesell.'; H. 206, Berlin, 1912.*)

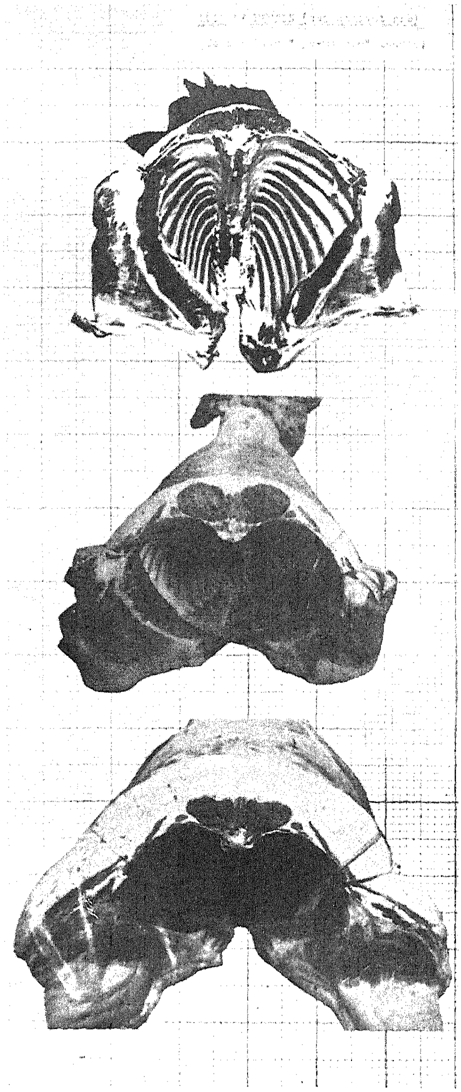

FIG. 6. LOINS OF MUTTON (cut at last rib)

To show where the fat-measurements given in Fig. 7 were taken—at the narrowest part over the 'eye' muscle. The three carcasses illustrate:

Top: A carcass with too little fat and an insufficient thickness of 'eye' muscle.

Middle: A carcass which has the proportions of fat and muscle required by the public.

Bottom: A carcass in which the fat is much too thick.

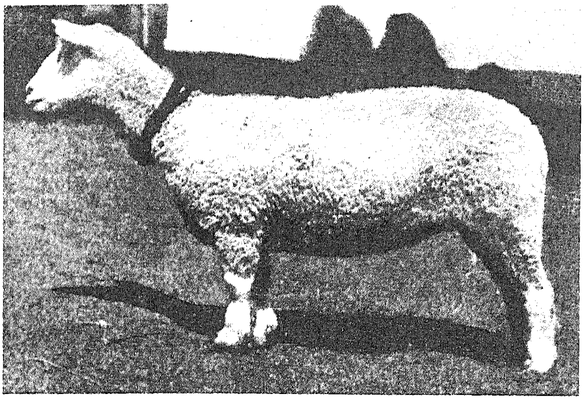

FIG. 8
THE ANCON SHEEP

The shortened legs are a recessive mutation and do not give intermediates on crossing with the long-legged type, as occurs when a breed with 'developed' short legs (such as the Southdown) is crossed with a long-legged type.

(*From Wriedt, 'Heredity in Live Stock', London, 1930.*)

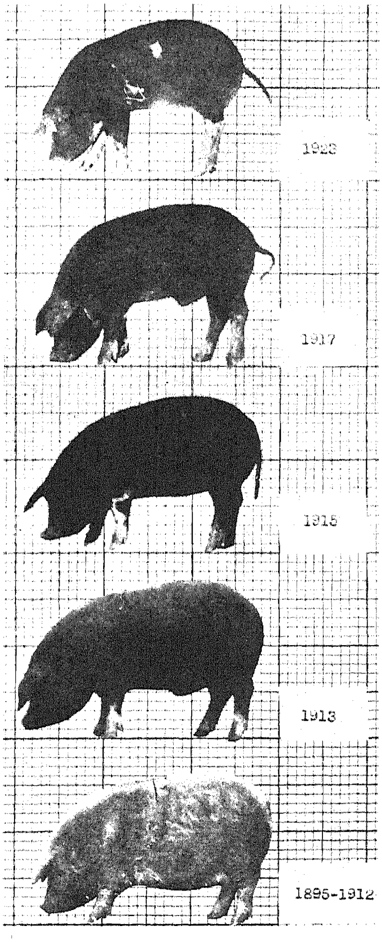

FIG. 9. CHANGES MADE IN THE POLAND-CHINA PIG WHEN THE DEMAND FOR LARD DECREASED

All the photographs have been reduced to the same shoulder-height to show changes in proportions as distinct from size. The breed has been changed by selection in the direction of later maturity, i.e. with more bone- and muscle-growth and less fat. These successive changes are the reverse of the changes which occur as the pig grows up. This has been attended with increase in actual size.

(*From Hammond, J. Roy. Agri. Soc., 1932, 93.*)

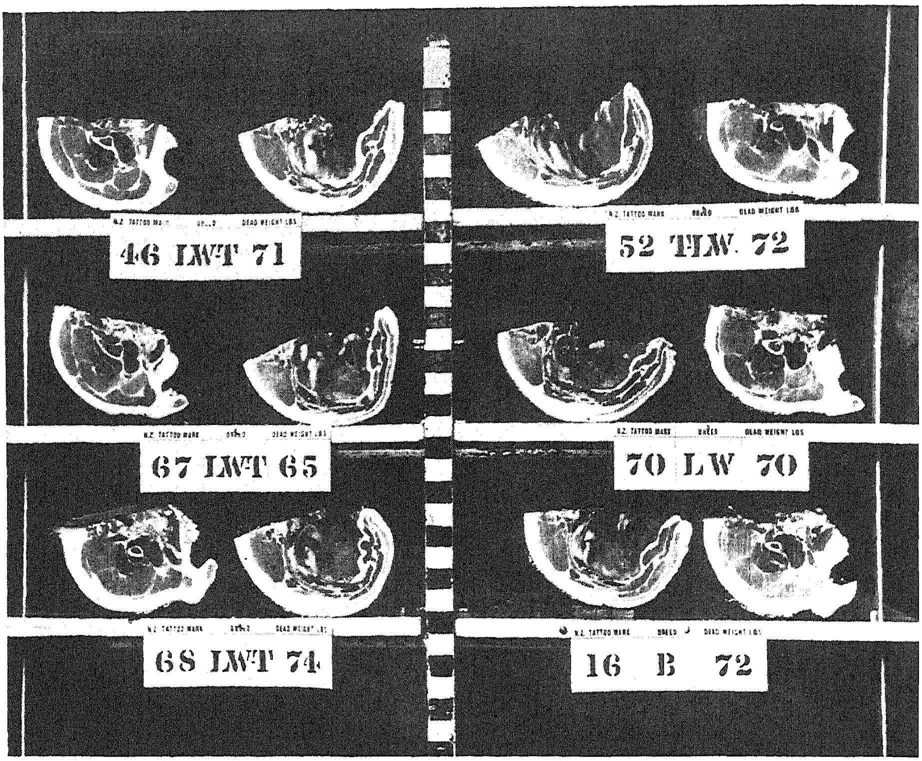

FIG. 10. CUTS THROUGH THE LEGS AND LOINS OF NEW ZEALAND PORKERS OF DIFFERENT BREEDS AND CROSSES

Nos. 46, 67, and 68: Large White × Tamworth; carcass weight, 71, 65, 74 lb.
No. 52: Tamworth × Large White; carcass weight, 72 lb.
No. 70: Large White; carcass weight, 70 lb.
No. 16: Berkshire; carcass weight, 72 lb.

Note on the loins the thickness of the 'eye' muscle, the uniformity and thinness of the fat over the 'eye' muscle, and the thickness and well-developed lean meat of the 'streak'.

(*From photographs taken for the Department of Sci. and Ind. Research, Wellington, New Zealand.*)

THE INHERITANCE OF PRODUCTIVITY IN FARM LIVE STOCK

II. MILK

A. D. BUCHANAN SMITH

(*Institute of Animal Genetics, University of Edinburgh*)

CAN the science of genetics offer reasonable help to the live-stock producer? If so, then by what means? In this paper it falls to me to deal with these two questions from the point of view of milk-production in cattle.

Before the scientist can tackle any problems he must be able to weigh or to measure that with which he is dealing. Both quantity and quality must be assessed. Thus genetical experiment in respect of eggs and milk is much easier than it is in the case of meat.

As Dr. Hammond has so clearly stated, it is essential to be able to discriminate between the factors affecting the productivity of an animal that are due to environment, nutrition, management, disease, &c., from those factors that are genetic. The difficulty of doing so is one of the rocks upon which the barque of the geneticist is most likely to founder; and the task is further complicated because attempts to correct for environmental and other variations are likely to mask a genetic factor. For instance, Mackintosh [1] has recently shown that, where it is necessary, for comparison, to correct the first-lactation-yield of dairy cattle, the correction factors employed often work reasonably well, but that in the case of one group of cows they were very far out.

Up till now, about 400 papers have been written dealing principally with some aspect of the inheritance of milk-yield. Some useful information has been obtained, but that source is now becoming exhausted, and I think that any future information of scientific value regarding the inheritance of yield and quality of milk will be obtained only by deliberate experimentation. By deliberate experimentation I mean the control of environment and nutrition to the greatest possible extent, so that, although the production of one generation takes place many years after the production of that ancestral generation with which it is to be compared, the comparison may be as straightforward as possible and with the minimum use of correction factors.

The need for this has been recognized by Dr. Graves and those in charge of the experiments conducted by the Bureau of Dairy Industry of the United States Department of Agriculture, and Dr. Lush informs me that several of the State agricultural experiment stations, such as Illinois and Nebraska, have now also laid down similar experiments with dairy cattle. This principle forms the basis of the experimental work that we are conducting with dairy cattle and pigs at the experimental farms of the Institute of Animal Genetics. The method adopted is to do our utmost to secure a uniform system of management and nutrition over a long period of years. There is no 'deliberate' experimentation. Results are being measured continuously. So far as I am aware, nowhere

else is this principle of holding environment, &c., reasonably constant being employed for dairy cattle. Yet it is precisely the same principle as that employed, though not for genetic purposes, by the most venerable of all agricultural research institutes. The 'classical' fields at Rothamsted, where certain plots have been under the same treatment for ninety years, form an excellent example of this method of passive research.

Already, and without the results of this planned and yet passive research, there is information of undoubted value, of which perhaps the most important is that quantity of milk is transmitted to a great extent independently of quality as measured by fat-yield. But many of the other results are still open to question. The problems that are now being tackled are not so much the determination of the number of genetic factors concerned in the transmission of total yield as the analysis of particular aspects of total yield, e.g. persistency of lactation. The various characteristics of the lactation must be considered in relation to each other.

In other words, we are not so much concerned with determining the number of genetic factors involved, as with analysing the lactation-curve of individual animals under a standard environment. (To ensure this, the greater number of the calvings occur in two months of the year.) Two cows may give the same yield of milk, but the one may give that yield in 200 days whereas the other takes 300: or the two cows may give the same yields in the same time but yet have widely different lactation-curves. These, therefore, must be studied with reference to the various qualities of the milk, amount of fat, sugar, protein, and natural minerals, as well as the colour, and size of fat-globule, &c., nor must the question of the relative weights of the cows be ignored both before and after the lactation. And all these are peculiarities concerning which we can already trace the workings of heredity. It is of fundamental importance to understand the action of these characteristics and their reaction on one another.

Thus it is small wonder that simple selection by the mating of the best to the best gives a large proportion of disappointing results. One cow may yield 2,000 gallons for one set of genetic reasons, whereas another cow will accomplish the same yield while possessing a very different constitution. There is, therefore, need for analysis.

Moreover, research of this nature will certainly discover whether abnormal modes of inheritance are operating, or whether quantity is simply a matter of multiple factors. These abnormal modes include such things as sex-linked factors, and those combinations of genes which act as inhibitors of yield. The existence of such modes of inheritance can easily slow down progress by simple selection.

Further, *economic* production may actually be best obtained when genes are in the heterozygous state. Personally, I do not think that this is the case in milk-production, though there are strong grounds for believing it to hold good for meat-production. In any case this is obviously a point that must be definitely ascertained: the required knowledge can only come from experiment.

A further point is to find out whether certain combinations of charac-

ters, desirable from the standpoint of the practical breeder, are genetically possible. For instance certain breeders desire cows giving 3,000 gallons of milk with 5 per cent. butter-fat. The analysis-stage might conceivably show this to be as impossible as the desire of other cattle-breeders to establish a roan-coloured breed, roan being a heterozygote of red and white.

A definite by-product of this type of investigation is that it enables a correlation to be made between the genetical and physiological factors affecting milk-production. No gene ever works directly on the character. Manifestation of the character follows some reaction of the anatomical or physiological structure. Inasmuch as this type of experiment provides what may be called the 'genetic yield', these yields may be correlated to certain post-mortem findings, e.g. to the size of the organs of internal secretion. The maintenance of a herd for genetic experiment thus provides the ideal material for research into the physiology of milk-secretion.

It is thus fundamental that, in applying the science of genetics to the complex problems of milk-production, the various genetic factors first be analysed. There can be no shadow of doubt that analysis is the prerequisite of synthesis. Meanwhile, patience must be exercised by those who would question the value of the application of the science of genetics. Rome was not built in a day, and the Romans built with stone, and not with cattle that require nine months to conceive and a further three years to produce.

With commendable reserve the United States Department of Agriculture [2] published only last year the results of the first planned experiment on the inheritance of milk-yield. It was a simple problem dealing with inbreeding. The experiment was begun in 1908, a quarter of a century previously. It has now been incorporated with a bigger experiment started about fifteen years ago, the results of which, I believe, will cause surprise to those who decry genetical experimentation with cattle on account of the slow rate of reproduction.

It can, therefore, be stated with some confidence that we now see our way round the Scylla of the disentanglement of the genetic factors. This does in part answer the question, but not wholly, for on the other side of the genetic ship looms up the Charybdis of the likelihood that the analysis will reveal so many genetic factors interacting with each other as to make the synthesis of the problem in its practical application almost an impossibility. An adequate reply to the opening questions of this paper demands the discussion of this point.

To those who have time to reflect, the practical outcome of the work of the plant-geneticist is little short of amazing. For many crops he has managed to make two blades grow where none could grow before. We animal geneticists have good cause for envy, and it is well that we should point out that this cause lies not merely in the greater rate with which one generation of agricultural plants succeeds another and the large populations which can be conveniently raised, but also in the fact that the productivity of a plant is as a rule infinitely more easy to measure and to assess than is the productivity of an animal.

The problem of an increase in the productivity of our live stock—and

the maintenance of that increase—is not so simple as, say, the problem of an increased yield in maize. Let me refer to the work of Winter [3], which has been recently the subject of some discussion. To quote 'Student' [4], Winter 'succeeded, by continuous mass selection, in producing two races of maize one of which has more than twice, and the other less than one third, the normal oil-content'. 'The movement of the means were, respectively, more than twelve and seven times the "inherent" standard deviation.' 'Student' estimates that at least 100 to 300 factors would be needed and considers that the actual number runs into thousands. Dealing with this point, Dr. Fisher [5] states that the experiment (which ran for twenty-eight years) is a direct demonstration that selection has the exact effects that selectionists have ascribed to it.

Can we do likewise if we breed our cattle upon the same principle of selection? There is no doubt that selection can greatly increase the productivity of scrub stock, but as the productivity of improved stock rises so does the rate of improvement decrease. The progress becomes so slow relative to the passage of years that we must now perforce accustom our ears to the astonishing slogan of certain advisers of our farmers that it is useless to use a bull that is out of a high-producing cow, a statement based on the fact that certain bulls of such breeding do not fulfil the expectations of the owner. Nevertheless the occurrence of such animals does fulfil the expectations of the geneticist.

It is curious that some of those of our practical advisers who most decry the simple selection embodied in the ancient rule of 'mate the best to the best' do themselves advise merely an elaboration of simple selection. So keen are these people on their slogan of the 'progeny test' as the salvation of the British dairy industry, that they go out of their way to decry past methods of selection—combined or not with pedigree. They quite ignore the point that the progeny test is merely the logical refinement of existing methods of selection.

There can be no doubt of the value of simple selection, combined with pedigree and the progeny test as a definite means for improving the productivity of our dairy cattle. There is equally no doubt that the rate of improvement is somewhat slower than it was. Granted time, patience, and money, can we reasonably expect that selection alone will effect the desired improvement in a manner such as Winter has shown to be possible with maize?

I do not think so. Without more fundamental knowledge, the rate of improvement is bound to get slower. The problem is not the simple one of selection for one particular object. In striving to achieve a definite race of high producers, we desire to obtain a multitude of characters each of which depends upon a multitude of genes. I do not suggest that it is worth our while to determine precisely the number of genes involved in, say, an increase in the sugar-content of milk. But what is definitely of value is to discover whether an increase in the sugar-content can be secured by simple selection, and whether it is genetically or physiologically incompatible with the selection of other important characteristics. Unless we know these things, selection is bound to bring in its train a considerable amount of disappointment.

But have we as yet obtained an adequate knowledge of the pure science of genetics? He would be a fool who would so presume. Take, for instance, Dr. Fisher's theory of the evolution of dominance: with Nature as the agent of selection it is essential that those characters which benefit the organism be transmitted in a dominant manner. Dominance is therefore acquired by such characters, though we are ignorant of the means by which it is acquired. With man as the selecting agent, it is of decided benefit to the species that the desired characters (i.e. the productive characters of our live stock) be transmitted in a recessive manner. At present they most decidedly are not. Is it possible that just outside our sphere of knowledge there exists a mechanism for the evolution of recessivity?

But such an hypothesis as the evolution of recessivity demands systematized inbreeding for productivity. The outcome of the recently published work of twenty years' inbreeding by the United States Bureau of Dairy Industry [2] shows great possibilities in the direction of stabilizing a high yield (1,700 gallons) by this method. Success in inbreeding demands, however, a certain knowledge of the mode of inheritance of the character and particularly if sex-linkage is operating. Here is a further reason for research both pure and applied.

The demands of the market are not stable. The consumer of agricultural produce is—to the producer at any rate—fickle in his likes and dislikes. Supposing selection to be more effective than I am willing to admit, it is bound to take at least twenty years to obtain the desired type. In the meantime the taste of the consumer is sure to have changed. Not only is the taste of the consumer liable to alter in twenty years, but the general methods of production are also likely to be revolutionized by circumstances over which the British farmer has no control. Unless we have fundamental knowledge concerning the inheritance of the characteristics of the lactation, we need not hope to be able to keep pace with market fluctuations.

Pending adequate analysis of the problem, a continuance of existing selection methods (with the re-enforcement of the recent remarkable rediscovery of the progeny test) is much to be desired and will, on the whole, give good results. When, as is bound to happen, there is a popular reaction to the progeny test—not because it has failed to give results, but because those results have not been as great as the advocates of the test are now promising—then the science of genetics will be able to make a further and definite contribution to the subject, provided that the foundations for such work have been well and truly laid.

Furthermore, the productivity of our live stock depends upon the close interrelation of the control of disease with nutrition and genetics. The Scottish shorthorn was not the product of Amos Cruickshank of Sittyton. It was the product of Cruickshank and turnips and straw—all three of them from Aberdeenshire. Likewise, the Aberdeen-Angus was not the product of McCombie, but of McCombie, turnips, straw, and oil-cake. As the biologists and farmers of Aberdeenshire fully appreciate, the science of the nutrition of our live stock is making great headway. But it cannot outstrip the genetic application. Improved methods

of feeding put new stresses on the machine that can only be met by the adjustment of the hereditary constitutions of the animals. At present we lack the basal knowledge necessary to effect such alterations which the future will certainly demand.

Let me illustrate this. Hitherto the 'basal ration' has been a most useful conception in the theory of feeding live stock. In Edinburgh we have two strains of pigs. For the one, the average consumption of meal, per lb. of liveweight gain, is over 4 lb.; for the other, the economical pigs, it is only about $2\frac{1}{2}$ lb. The same holds good for cattle, both for milk and beef. Thus, by genetical methods, the interior economy of an animal can be modified to suit nutritional requirements.

Finally, to those critics of the genetical method for the improvement of our dairy cattle, I would say: It is worthy of remark that the hereditary improvement in the yield of our dairy cows has taken place in the post-Mendelian era. The fact that the breeding of live stock has in part been reduced to a science has clarified thought and put the practice of live-stock improvement upon a logical basis. Moreover, each new generation of breeders has no longer to disentangle fact from fancy. The existence of the science enables the young breeder to start at the place where his father left off. This is no mean achievement to the credit of the science of genetics, for it must be remembered that, whereas the improvement of the hereditary qualities of crops rests safely in the hands of a few skilled research workers, the improvement of our live stock rests with the innumerable breeders of that live stock distributed throughout the world.

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THE INHERITANCE OF PRODUCTIVITY IN FARM LIVE STOCK

III. BREEDING FOR EGG-PRODUCTION

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DISCUSSING the future possibilities for increasing egg-production in poultry, Jull [1] has stated that progress largely depends upon the poultry breeder's ability to control heredity. Further, he suggests that 'heredity can be controlled and directed best only when the knowledge of poultry-breeders develops sufficiently to enable them to select breeding stock that will transmit to their offspring the most desirable qualities. Selection is the keynote in the programme of future development.'

Selection without an exact knowledge of the mode of hereditary transmission of desirable qualities, but with a belief that they are transmissible from parent to offspring, has been the basis of all breeding practices in the past. It has been responsible, together with improvements in husbandry, for the tremendous increase in the production records of our modern domesticated breeds when compared with the ancestral types from which they have sprung. Such advance bears witness to the importance of heredity.

In attempting to assess the possible value of the science of genetics to the cause of increased fecundity in poultry, we should begin by considering the results that are now obtainable when selection along certain definite lines is practised. An examination of the production figures at egg-laying contests testifies to the skill of the intelligent breeder in developing highly fecund strains of birds. His methods of selection, however, when improved flocks are dealt with lead to negligible progress over a fairly long period of time. This has been demonstrated by Dunn [2] from an analysis of egg-laying contest figures in America. Over a period of nine years he found that there was little material change in average egg-production. This is very significant. Since only a small percentage of a flock of birds is rigorously selected by certain standards for participation in egg-laying trials, it follows that the results obtained represent *practically* the highest individual performances possible with the methods of selection now used by breeders. The production of the flock as a whole, however, usually falls far short of these individual records, and perhaps the most pressing question to be faced from the economic standpoint is that of devising a means of raising the figure for average production, even in the most improved flocks.

The problem of improving egg-yield by breeding has been the incentive to much scientific work, which has taken the form of analytical attempts to define and measure the desirable qualities that a hen should possess in order that maximum production may be attained. From observation and experiment Goodale and Sanborn [3] conclude that there

are at least five desirable qualities which, if present in a bird, lead to high annual production. These are:

1. Early sexual maturity.
2. High intensity of production.
3. No winter pause in production.
4. Non-broodiness.
5. High persistency of production.

Even a casual acquaintance with the hen reveals that for certain periods in her reproductive life egg-production ceases for varying lengths of time. The most definite gap in egg-laying occurs during the time when the old plumage is being discarded and the new feather-covering is growing in. Since this is a characteristic annual phenomenon, typical of the vast majority of birds, it will be seen how important its effect is upon the annual-production record of the pullet—a figure which is arbitrarily fixed as the number of eggs laid in the 365-day period from the time when she produces her first egg. Since the moult is very variable, both in point of time and duration, it is obvious that the annual production increases in proportion as the onset of the moult is retarded and approaches the end of the 365-day period. At the Institute of Animal Genetics, Edinburgh, we have several hens among our flock that, over a two-year period, have failed to undergo the moult, and egg-production has not ceased during this time. This is the ideal persistency.

High intensity means that a bird must be persuaded to lay as often as possible within the prescribed period. 'Winter clutch size', i.e. the average number of eggs laid in succession up to March 1, is used as an indicator of intensity of production, because it has been found to be significantly correlated with annual egg-production.

Most pullets are hatched so that they become sexually mature in the autumn. It is rarely found, however, that continuous production occurs throughout the winter months without the appearance of at least a few successive days on which no eggs are laid. A break in the continuity of production of this magnitude classifies the bird as exhibiting 'winter pause'.

Another physiological manifestation that affects the ultimate performance of a hen is that of broodiness. During this phase of maternal expression, egg-production ceases for a variable length of time, and is recommenced only after the signs of broodiness have waned. This is a problem which affects particularly that branch of the industry concerned with the heavy breeds of poultry; broodiness is a comparatively rare phenomenon in leghorns, for example.

Recorded observations of many workers have shown that quick-maturing pullets tend to make the highest annual records, and this emphasizes the necessity for considering early sexual maturity when increased records are desired.

These five qualities are, perhaps, obvious ones to select for, if an increase in egg-yield is desired; it will be interesting to see what amount of improvement may be obtained in a relatively *unimproved* flock by continuous selection along these lines. Fortunately, the results of two

separate experiments are available, one carried out by Marble and Hall [4] and the other begun by Goodale and continued by Hays and Sanborn [5] (Table 1).

TABLE 1

Marble and Hall, 1930.	Goodale, Hays and Sanborn, 1934.
Leghorns.	*Rhode Island Reds.*
Average production increased from 118 to 196 eggs.	Average production increased from 134 to 222 eggs.
Percentage increase 66·1.	Percentage increase 65·6.

It is not suggested that such a rate of improvement could be obtained in the best flocks by means of selection based on the five qualities outlined above, because in all probability the higher averages produced nowadays have resulted from an unconscious use of these qualities as a basis of selection over a comparatively long period of years. Both experiments started with birds that did not give a very high average egg-yield, and continuous selection for increased egg-production was maintained over a period of twenty years. The results obtained in both sets of experiments showed a remarkable similarity in the amount of increase in the average yield, and this is the more striking when it is considered that not only were different breeds used, but that the initial egg-production of the two flocks was also different. From these experiments it is possible to deduce that the methods employed are along the right lines, but the question has still to be faced as to what is the final degree of improvement in egg-yield that may be obtained by these methods.

From an analysis of their flock records for the years 1928 to 1932, Hays and Sanborn [5] show that whereas over 50 per cent. of their birds exhibited three or four of the desirable characteristics, and 16 per cent. all five of them (Table 2), this improvement was only about one-sixth of that theoretically anticipated, for there is no known reason why all the birds cannot carry all five desirable characteristics.

TABLE 2

Relation of Number of Desirable Characters to Annual Production

Characters. Number	*Birds. Number*	*Birds. Per cent. of total*	*Egg-production. Average per bird*
0	31	1·3	149
1	158	6·9	157
2	375	16·3	174
3	717	31·2	201
4	648	28·2	227
5	371	16·1	252

That these particular desirable characters are inherited has now been established and a reasonable idea of their mode of inheritance has been gained.

Early sexual maturity apparently depends on two independent dominant genes, either of which can produce, for example, the onset of egg-laying in the Rhode Island Red breed before the hens are 215 days old. One of these genes is sex-linked, the other autosomal (Eo and E′E′).

For high intensity of production, also, two dominant genes are necessary (II and I′I′). Hens carrying gene I have alone an average winter-clutch size greater than 2, but less than 2·6. Gene I′ gives a clutch size of about 2·6. Both genes together increase the clutch size up to 3 or more eggs throughout the winter season. Both genes are autosomal and cumulative in effect.

For winter pause there seems to be only one dominant gene, M. Desirable birds therefore carry the recessive form, mm.

Broodiness has been found to be inherited on a two-factor basis. Two dominant complementary genes, A and C, are necessary to produce it. There is no evidence of sex-linkage and non-broody birds are of three general classes: (1) those lacking both A and C; (2) those carrying A and lacking C; and (3) those carrying C and lacking A. The latter two classes make it evident why broodiness is so difficult to eliminate *completely* from a flock, since females of these constitutions, though not exhibiting broodiness themselves, will produce broody offspring if mated to males carrying the complementary gene they lack.

The data for persistency indicate that it is inherited on the basis of a single dominant autosomal gene, P.

So far as experimental work has shown, the ideal hen should have a genetic constitution, with regard to the desirable characters leading to high egg-production, as follows: Eo, E′E′, II, I′I′, mm, aacc, PP.

It will readily be seen why progress by methods of selection is apt to be extremely slow, for there are possible in a flock, 65,496[1] genetically different classes of birds with regard to the five characters involved, and only one of these would give fixity of type. Again, since five of the eight genes, from which these characters originate, are dominants, distinctions between their heterozygous and homozygous forms are small, and at present apparently undetected, so that if, as must occasionally occur, a hen homozygous for all the desirable qualities should arise, the chances of its being recognized as such are extremely small. In the case of the male, the difficulties are further increased by the fact that, though for true-breeding stock he must carry the desired characters in the homozygous form, yet he cannot in himself exhibit them.

It can well be imagined then that the chances of producing a strain with constant genetical constitution is extremely remote when selection methods alone are practised; and it is indeed doubtful whether much further progress would be made in the best flocks, although considerable progress is possible in unimproved stock.

If we refer back to the original statements of Jull that 'the possibility of increasing egg-production depends on the poultry breeder's ability to control heredity', and 'that selection is the keynote in the programme of future development', a certain amount of confusion arises. Even with the knowledge of the mode of inheritance of the necessary qualities leading to high annual egg-production, it cannot be said that a policy of selec-

[1] This figure is taken from Hays' publication but is obviously incorrect. The number of genetical classes possible when dealing with eight genes, only one of which is sex-linked, would be 4,374 when females alone are considered, and 6,561 if males are considered: a total of 10,935.

tion along these lines owes anything to the fact that a genetical analysis has been made. In fact, it may be said that ignorance of the genetical work should produce about the same amount of improvement in a flock, because the qualities selected for are just those which, if inherited, would tend to increase production. So far, the service of genetics has been to prove what has hitherto been a belief, viz. that certain desirable qualities are inherited in a definite and orderly manner.

Unless we are to agree with Babcock and Clauson [6] that the real service of genetics to animal breeding lies in promoting clarity of thought, the geneticist must show how the knowledge gained by experiment can best be used to improve existing breeding practices. In this particular field he must show the breeder how he can control heredity.

The real limitation of selection lies in the fact that, owing to the apparent similarity of production of the homozygous and heterozygous gene groupings, it is impossible to forecast with accuracy the productive capacity of all offspring from any mating. To illustrate this with regard to one particular quality, say persistency, making use of genetical knowledge, let us suppose that only females showing persistency were selected as breeders; they would have either the genetic constitution PP or Pp. There could be no evidence from the male himself as to his genetic constitution, and so, from matings with persistent females, there are three groups, each of two classes, into which his resultant progeny might fall (Table 3).

TABLE 3

	Parents	*Offspring*	
Group 1.	PP♂ × PP♀	PP	all persistent and true-breeding.
	PP × Pp	1 PP : 1 Pp	all persistent, but only half true-breeding.
Group 2.	Pp♂ × PP♀	1 PP : 1 Pp	all persistent, half true-breeding.
	Pp × Pp	1 PP : 2 Pp : 1 pp	three persistent to one non-persistent, but two in three of persistent not true-breeding.
Group 3.	pp♂ × PP♀	Pp	all persistent, but not true-breeding.
	pp × Pp	1 Pp : 1 pp	one-half persistent, but not true-breeding.

The fact that females exist in the stock which exhibit persistency, and yet cannot transmit this quality to all their offspring, makes it extremely unlikely that, using this as a basis of selection, a strain homozygous for the character would ever be developed, even though care was taken to breed only from birds all of whose progeny were persistent. Such a procedure could only tend to limit the selection of breeders to the first three classes, and since only the first is of fixed constitution, a certain number of undesirable, i.e. recessive, individuals would almost inevitably occur among the succeeding progenies, which might belong to any of the first four classes.

Genetical work has given us at least one clear conception, namely, that a bird may exhibit a desirable character, but only be able to transmit it to part of its offspring. The immediate application of this knowledge could only be made if further experiment were carried out in sufficient

detail to demonstrate whether measurable differences between the hetero- and homo-zygous forms exist. If this could be done, then the development of homozygous strains carrying all the desirable characters, could be rapidly undertaken. Only by this means can the control of heredity by breeders be readily visualized.

On the other hand, should this information be unattainable, that is, supposing measurable differences in egg-production cannot be found between hetero- and homo-zygous forms, the geneticist still has a method of attack that would eventually lead to the analysis of the genetical constitution of any bird. In the first place it would be necessary to build up a stock containing all the homozygous *recessive* forms of the characters to be investigated. This could be done by selection much more easily than by the reverse process. The value of selecting for recessive characters is well illustrated by the results of selection against broodiness; this has been almost completely eliminated from many breeds of fowl, and even in breeds like the Rhode Island Red, where broodiness is of common occurrence, the value of selection against it is shown in the figures of Hays and Sanborn, where the percentage of birds exhibiting this characteristic phenomenon dropped from 86 in 1916 to 12 in 1932. Theoretically then, the building up of a strain of birds homozygous for the recessive characters should not offer great difficulty. Such birds would have the following genetical constitution with regard to the characters selected against: eo, e′e′, ii, i′i′, pp, aa cc, (late maturity, low intensity, low persistency of production and non-broodiness). The only character of the group that would offer any difficulty would be winter pause, which depends on a single dominant gene. The recessive homozygous form could not be expressed in such a strain of birds because of the activity of the other genes selected to give minimum production; this hindrance could be overcome, however, by first of all fixing this character in the stock from which the homozygous recessive strain would subsequently be developed.

Having once obtained such a strain of birds, it would be possible to determine accurately, and well within the productive life of the bird, the genetical constitution of any male or female, by means of matings with the recessive stock. The desirable qualities, which combine to produce high egg-yield, are most probably dependent on the same genes in the different varieties of the domestic fowl, so that it would not be necessary to obtain testing strains for all the different breeds of fowl.

Before closing this discussion of the inheritance of egg-production it is necessary to emphasize the fact that the survey of the problem has been made from the simplest possible genetical angle. We have dealt only with the behaviour of certain inherited characters without suggesting factors that might intervene to complicate breeding practice, and so we have omitted to stress the important role played by environment and its effect on the expression of the gene. It is obvious, however, that this type of reaction also falls within the province of the geneticist—to determine how the expression of the genotype may be modified under varying environmental agencies. It goes without saying, for instance, that nutrition plays a most important part in deciding, whether or not, the full

genetic capabilities of an animal are to be expressed. Apart from nutrition, perhaps the most striking effect on egg-production derived from control of extraneous environmental influence is that which follows increased exposure to light.

Just as we have a measure of the intensity of inheritance from observations on parent and offspring in breeding practice, so, to determine quantitative effects of environmental factors on gene expression, it is necessary to have stock whose genetical constitution is known.

There is yet another phase of genetical inquiry that may perhaps be considered of mainly academic interest, but from which we now have indications that it may lead shortly to more practical and less tedious methods of controlling heredity than that outlined earlier in this paper. In the final genetical analysis the gap in our knowledge which exists between the presence of the gene, on the one hand, and the exhibition of its end-product—the character—on the other hand, must be bridged.

Hammond [7] has given us a suggestion as to the type of mechanism that may lie between the genes and their characters. In the experiments on the increased productivity due to an increased light ration, it is his opinion that light acts by stimulating the anterior pituitary gland to increased secretion, and this substance circulating in the blood stimulates in turn the ovary to increased production. He further suggests that the level of this substance in the blood may explain the difference between high and low egg-producing strains and breeds.

It would be interesting to determine which of the five qualities outlined previously as leading to increased egg-production are likely to be affected by this stimulus.

Early sexual maturity.—The relation existing between sexual maturity and the anterior lobe of pituitary is too well known to need labouring, but the work of Domm [8] in Chicago merits a brief notice. By suitable injections of a preparation of this gland, he was able to produce precocious development in the sex glands and secondary sexual characters of fowls, so that some of his male chicks were crowing nine days after hatching, and began to tread when only a fortnight old.

Persistency.—The length of time a bird continues laying after the production of her first egg is limited by the time of appearance of the moult. In one of our birds we were able to eliminate the moult by implanting anterior pituitary glands from other birds (Greenwood [9]).

Broodiness.—From extracts prepared in our laboratory, Professor F. A. E. Crew has been able to produce the typical behaviour of broodiness in Leghorn fowls, a breed in which it rarely occurs. Even young hens reacted to the stimulus before sexual maturity was reached.

Intensity and no winter pause.—Gutowska [10] has shown that oral administration of anterior lobe of pituitary leads to an increase in egg-number. There was an increase in the number of follicles in the ovary, and also an increase in their size. The results were most striking in the early part of the year (before spring).

Finally, Parkes [11] has shown recently that the removal of this gland leads to the atrophy of the sexual glands.

I have purposely avoided entering into too much detail with regard to

these extremely significant observations, since at the present time control of heredity by these means remains still in the realm of possibility and has hardly reached the fringe of probability. An immense amount of work still remains to be done.

Summary

1. Selection methods practised along the right lines tend to increase productivity, particularly in unimproved stock, but progress is slow in improved stocks because of the inability of the breeder to control heredity.

2. It has been shown that the desirable qualities to select for are inherited and that their mode of transmission from parent to offspring has been determined.

3. Such knowledge need not necessarily affect selective breeding practice because of the present inability to distinguish between hetero- and homo-zygous forms of these genes.

4. The application of genetical knowledge to breeding requires either a method of distinguishing these forms by their production records, or an accessible technique whereby the genetical constitution of an animal may be accurately determined. With this knowledge at disposal, the fixation of desirable characters in a flock can be readily made.

5. The field of work of the geneticist covers not only the mode of transmission of characters under optimum conditions, but also the effect of variations in the environment on the resultant expression of gene action. For this it is essential to deal with animals of known genetic constitution.

6. The final phase in the genetical analysis concerns the relation between the gene and the mechanism by which the end result—the character—is produced. The possibility of the control of heredity through the control of physiological processes is foreshadowed.

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THE INHERITANCE OF PRODUCTIVITY IN FARM LIVE STOCK

Pt. IV. WOOL

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The general title of these papers suggests a wider field for consideration than that simply of the inheritance of wool-characters, which has been reviewed recently by Miller [1]. In the first place, it is to be remembered that the fleece, as a covering during life, contributes to the hardiness of the animal in its ability to survive the rigours and changes of environment, and is therefore concerned in the other activities of the sheep, for meat-production, for breeding surplus stock, in some countries for milk, and so on. It is an agent, though indirect, in promoting the efficiency of the sheep as a producer of those commodities which the sheep-breeder hopes will be profitable to him. Herein it gives rise to problems in productivity rather remote from those occurring in the other animal products dealt with in these articles.

Fibre-growth is a more intimate function of the sheep's activity than is, say, milk-production of the cow's and egg-production of the hen's. It begins in early foetal life and ends only at death. There would thus appear to be three different primary sets of environmental conditions to which it is exposed, viz. (1) the relatively constant foetal environment, during which, however, the follicles *inter se* are affected by the sequence and density of their development [2], (2) the early post-natal, representing a change in life-habit towards (3) the post-weaning, quite independent life, in which the animal attains maturity, becomes a functional ruminant, and so exposed to all the exigencies of nutritional environment incidental to free-grazing animals.

The changes that occur with general development are obvious in many breeds. Many Merino lambs are born hairy; the birth-coat hairs are shed or lost, and leave the growing lamb with a fleece of practically pure wool. The lambs of some of our Down breeds, especially the Suffolk, are more or less darkly coloured at birth; by shedding and replacement, the relatively pigment-free adult coat is acquired; from maturity onwards we find other changes in fleece character. Recent work on time or age changes, from birth to maturity, is pervaded with the idea that definite relationships exist between natal and adult coats, and that selection for desirable adult fleece-characters can be exercised early in life [3]. It is clear that not only is the follicle-population variable in time, but also the forms of the fibre-product are alterable.

Throughout the adolescent and mature phases the changes in fleece-growth that can follow alterations in nutritional level are very varied, and may be of some magnitude. For example, in one case, which has been studied, of an Australian Merino fleece, it was estimated that in terms of average fibre-volume per month, the rate of production

suddenly accelerated by over 100 per cent. at one period of the year [4]; and the wool-fibres are not the only products of the skin-and-follicle system which make up the growing fleece [5].

But so far as wool-productivity is concerned, we are mainly involved in considering wool as an annual crop of some direct value to the farmer. For the most part its course to the real consumer is peculiarly tortuous and prolonged, and through the innumerable mixings which occur the individual fleece loses all its identity. The cash value of the wool crop to the farmer is ordinarily some function of the weight of raw wool, the proportion of grease and other non-wool materials in the raw fleeces, and the estimated fitness of the amount of actual pure wool present for particular manufacturing purposes. These three factors are very variable, from one animal to another, from flock to flock, between different breeds, and according to locality and husbandry. Moreover, when the wool-using industry is viewed as a whole it is readily appreciable that absolute uniformity of the supply of raw material is not desirable. Of the inherent attributes of the wool-fibres in the fleece which affect its manufacturing utility, length, soundness, 'quality' or fineness, uniformity, trueness to its particular type or breed, and general character, may be mentioned, but of these only length and fineness are readily measurable, and have therefore been studied most.

The most useful combination of these characters from the manufacturer's point of view is not necessarily that which the farmer would consider optimal, quite apart from other attributes of the fleece with which the latter is concerned. For example, fleece-density, in part contributory to fleece-weight, is of more direct interest to the breeder than to the user, in so far as it is involved in the rain-coating action of the fleece. Yet it is apparently not always dissociable from the length-fineness complex.

In view of such interrelations it is perhaps not surprising that the majority of investigators conclude that apart from questions of colour, the inheritance of most fleece-characters is dependent upon multiple factors.

Apparently conflicting results have, however, been noted. For example, whilst Hill [6] found the F_1 intermediate in wool-fineness in Hampshire-Rambouillet crosses, Davenport and Ritzman [7] noted that the F_1 approached the *coarser-woolled* Hampshire parental type; yet these investigators also describe intermediate F_1s in crosses involving Southdown and Oxford rams and Rambouillet ewes with a tendency to approach the *finer-woolled* parent. At the same time, they record in the Oxford cross an F_1 wool-length approximating that of the Oxford, suggesting dominance of the longer-wool type, whilst in the Southdown and Hampshire crosses, the F_1 had longer wool than either parental form. Observations on Scotch Halfbred (Border Leicester ram × Cheviot ewe) also indicate partial dominance of the longer wool, but if amount of fibre (i.e. volume) is considered, then these conclusions may have to be modified, since in this cross the F_2 average fibre-volumes tend to swing towards the Cheviot parental type rather than the Border Leicester [8].

If we admit that multiple-factor systems determine fleece-character inheritance, two important considerations arise. The first is the apparent

futility of searching for single genetic factors which may override or profoundly affect the fleece-complex of wool characters. Miller [1] has raised this point, but re-emphasis is not out of place. The second concerns methods and degrees of selection. The suggestion can be made that some of the divergent results of investigations are explicable on the grounds that one parental form has been selected more rigorously, or is less heterozygous, for one particular fleece-character and exhibits a degree of prepotency, just as in ordinary breeding practice appear strains or individuals decidedly impressive. Conceivably, such an interpretation may be applicable, for example, in the first and second generations of the Border Leicester-Cheviot cross, which show bimodal frequency distributions of fibre-length similar to those found in the Border Leicester [8].

Selection for wool-productivity is in practice pursued within the single breed or flock; in ordinary husbandry its objects are generally to reduce the variability of fibre-character on each animal and from one animal to another, i.e. within the flock or breed, as well as to improve performance in some desired direction, such as greater density, higher fleece-weight, better yield or longer staple. Outstanding examples of the progress of such selection are to be found among the 'stud' Merino flocks, and from them we can draw conclusions, not only as to the methods of improvement, but also as to the ways in which the geneticist may accompany the practical breeder.

In multiple-factor situations, the phenotype closely reflects the genotype. In the stud flocks we find that whereas first selection may be phenotypic, the progeny test is widely applied, and the method of breeding involves a progressive infiltration of a genotype throughout part of the flock. Thus, briefly, a stud ram will be mated to a few selected stud ewes, some of his ram offspring will be mated to other stud ewes, and so on until, when proved, his influence can be applied where necessary in the flock. Even in the larger commercial flocks some selected ewes are retained almost solely for use with introduced rams, to breed rams for general service, forming a ram-testing and breeding flock within the main flock. But the function of the studs, or pedigree flocks, is to supply so-called 'flock rams' for use elsewhere, which means, in many different environments. The breeders realize the importance of the extraordinary effects of environment on the animal and its fleece; hence a certain variability of genotype is deliberately maintained so that the different demands for flock rams may be met. To this end the variability is kept possibly relatively greater among the top stud animals than among the flock ewes.

But in surveying the wool-producing countries one cannot help being impressed by the remarkable way in which certain localities are pre-eminent for selection and improvement, constituting in effect centres for the breed from which emanate stock for commercial use in other areas. The type most successfully or most readily developed in one breeding centre is, however, not necessarily very like that from another. Further, they do not perforce react in precisely the same way when transported to yet another environment.

A few instances from the many may be quoted. In the British Isles

is a multiplicity of breeds, almost every one possessing a territory within which it either predominates or produces stock for crossing, and there are also local variations in type of practical importance. In Australia, among the Merinos, are the South Australian, the Riverina, and other New South Wales forms of strong wools; stocks of strong or medium-wool origin exhibit different characters when pastured in fine wool areas, whilst among the fine wools distinction can be made, for example, between the Tasmanian, Victorian, and New South Wales types. Parts of the Karroo areas in South Africa form fountain heads of improved breeding stock for use in other regions of the Union, and in New Zealand, among the Romneys, different localities apparently demand different strains.

In all cases it is, or should be, the general balance of fleece-characters that is borne in mind. Only a few days ago, discussion with a New Zealand breeder revealed that he had been attempting to increase his fleece-weights by selecting for greater staple-length, but he had found that at a certain stage the wool suffered by the tips of the staples becoming more weathered and wasted. Thus it was better to sacrifice the extra length and weight for soundness throughout the staple.

All these considerations add force to the principle that the pre-requisite for selection is that environment which allows the clearest expression of genotype. In the field of wool-productivity, to aid in the recognition of genotype and to gain accurate knowledge of phenotype to which it gives rise in other environments, are objectives which the zoologist may well pursue.

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THE INHERITANCE OF PRODUCTIVITY IN FARM LIVE STOCK

Pt. V. DISCUSSION OF PRECEDING CONTRIBUTIONS

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Clarity may be served by discussing these four papers from two standpoints: firstly, the inheritance of productivity as a scientific fact, or series of interrelated facts, and secondly the methods of using those facts and interrelations most efficiently to advance the aims of animal breeders. Efficient application of fundamental knowledge to the solution of present problems may not automatically follow the discovery of that knowledge. Research in methods of application may be quite as necessary as research in discovery of the principles themselves.

So far as concerns inheritance, each paper has stressed the complexity of the topic. It seems certain that for each trait there are many genes involved. No doubt these genes interact with each other and with the environment in many ways besides the simple additive way that may be expressed most readily in generalized formulae.

Each paper has also stressed the necessity for keeping the animals in an environment that would permit differences in productivity to develop, although the philosophical explanation for this necessity varies among the speakers. Dr. Hammond holds that the genes change adaptively in direct response to the environment, whereas most of us hold that such gene-changes have not been demonstrated experimentally, even by the many experiments expressly intended to find them, and, moreover, are not necessary to explain the facts, either of animal breeding or of evolution. Hence we would argue that there is no necessity for invoking such a supposed direct effect of environment on genes, even as a working hypothesis. The necessity for keeping animals under an environment that will permit them to show their differences in productivity, arises from the fact that conscious selection for such differences is possible only when and as far as such differences are permitted to develop to a recognizable degree.

The sharp line which Dr. Hammond proposes between 'developmental' and 'mutational' characteristics will not, I think, be accepted as valid by many workers, either in animal breeding or in more classical branches of biology. Most of us would hold that all characteristics are developmental, depending for their full expression upon the interactions of the genes with each other and with environment as well. From this standpoint, highly hereditary characteristics are those in which most of the variance we ordinarily see is due to differences in the genes which different individuals have, whilst faintly hereditary characteristics are those in which most of the variance ordinarily occurring is due to differences in environment to which different individuals have been exposed. Characteristics may further be classified according to whether the hereditary portion of the variance is due to few factors and shows sharply

discontinuous classification, or many genes are involved and yield a practically continuous series of phenotypes. From this standpoint the differences between highly hereditary and slightly hereditary, or between continuous and discontinuous, characteristics, although highly important practically, involve no differences in fundamental principles, but only differences in the number of genes involved, or in the proportions of the total observed variance resulting from genetic differences and from environmental differences.

So much for the fundamental facts concerning the inheritance of productivity. Before applying those facts to breed higher productivity into a breed or strain of animals, as an engineer would apply the fundamental principles of physics and mechanics to such a task as the building of a bridge, measurements are needed of the magnitude of the forces involved, just as the engineer would need measurements of the loads his bridge was expected to carry, the amount and seasonal distribution of the water-flow which must move down the stream under it, the number of years before it is expected to become obsolete, the amount of money available for construction, &c. I venture the opinion that in general this is the least explored field of applied genetics, and that neglect to measure and integrate properly these variables is the major cause for the mistakes and unsound proposals that are sometimes made, even by those whose knowledge of biological fundamentals is not seriously deficient.

It will not have escaped notice that all four speakers have mentioned selection as a first step in breeding for productivity, although they differ considerably in their optimism as to its *sufficiency*. I would here call attention to only two aspects of the question of how intense selection can be, even in the idealized case where the man doing the selecting is possessed of complete knowledge of the genotypes of his animals. The first is that natural fertility and longevity set serious limits to the intensity of the selection which may be practised. Each parent must eventually be replaced by another, even in a population static in size. What proportion of the female offspring must be saved for replacements? What proportion of the males? Here is a whole field of what we might call 'the vital statistics of farm animals' which is as yet only slightly explored. In dairy cattle, about 50 to 60 per cent. of the heifers must be saved, merely to replace their dams, which are being lost by disability, old age, and other causes of death. In swine, perhaps 10 per cent. of the gilts would be enough; perhaps 7 or 8 per cent. would be enough in exceptionally well-managed herds. In chickens, perhaps 2 per cent. of the eggs that might possibly be hatched into pullets would be enough for replacements. These figures set serious and varying limits to intensity of selection in the first place. One must begin with the material available. There is small use to talk of the advantages of selecting breeding-stock homozygous for high productivity if less than 1 per cent. of the population is of that genotype, and if one is forced by reproductive rates to save 10 or 50 per cent. of the whole population for breeding.

The second point concerning the intensity of selection is that such intensity is weakened (much more than is generally realized) by the inclusion of more and more items in the ideal; that is, by considering

many different characteristics in making the selections. In the idealized case, where n independent, equally important characteristics are to be considered in the selections and x is the proportion of the population which must be saved for replacements, the selection intensity for each characteristic singly is the same as if the nth root of x were the proportion which must be saved. Thus, if one needs only to save one-tenth of the offspring, but pays equal attention to eight independent characteristics, the intensity of selection for each such characteristic is no greater than if attention had been paid to the characteristic alone, but it had been necessary to save three-fourths of all offspring born. This, I think, is the only general basis of real antagonism between breeding for production and breeding for 'fancy points', namely, that each additional point considered must necessarily weaken the selection which might otherwise have been practised. Nevertheless, the practical breeder *must* pay attention to several things, even though he understands perfectly this weakening effect.

Besides estimating how intense his selections can actually be, one needs (if he is to estimate the outcome at all accurately) to know first what portion of the observed variance is genetic in the narrow sense, which includes only those gene-combination effects that can be expressed by some additive scheme; second, what portion of the variance is due to gene-combination effects that cannot be expressed additively; and third, what portion of the initial variance is purely environmental in origin. Of course such a division is not absolutely correct to the last detail, since in actual practice there will be interactions between the three kinds of variance. For instance, some genotypes may be more plastic to environmental influences than others. If that be the case, and if the breeding system increases the frequency of the more easily influenced genotypes, then the environmental portion of the variance will likewise increase, although the environment does not change. If extreme refinement is important, and if the necessary data are available, a more detailed division may be made specifying how much variance is due to such interactions. However, in most practical problems, such refinements will usually produce but small gains compared with the considerable amount of approximation still remaining. Usually, the first approximation given by dividing the variance into the three parts named above will be sufficient for the purpose of practical application.

Only the genetic variance that can be expressed additively is subject to simple mass selection. The refinements of selection methods, such as the progeny test or the judicious use of pedigree information, serve mainly to reduce somewhat the errors that are introduced by the other sources of variance. For instance, if one third of the variance in milk-yield of a breed of dairy cows is genetic in this narrow sense of the word, and if the breeders pay no attention to bulls, but select the cows so intensively that those saved for breeding average 150 gallons more than their entire contemporary generation, one can expect the next generation to average about 25 gallons above the generation in which their parents were born. When compared with the 150-gallon 'selection differential', the 25-gallon gain may appear disappointingly small. No doubt this

explains the fact that in every country the voices of zealous enthusiasts are sometimes heard proclaiming that the old methods of selection and attention to pedigree are useless, but that the latest panacea of progeny test, sire index, or what not, will accomplish all that the old methods are condemned for not doing.

In the example just quoted, the complete and exhaustive use of a progeny test for the selection of bulls, while still using the same standard of selection for the cows, could about double the rate of progress, the exact figure depending much upon what portion of the tested sires it is finally necessary to save for replacement purposes, and on what portion of the dams of the future breed are sired by bulls being tested, and what portion can be sired by bulls after they have been proven. Such a doubling of the rate of progress would be an achievement important enough to justify much enthusiasm for proven sires. Yet the point I wish to make here is that the difference is not between methods that are wholly right and methods that are wholly useless, but between methods of selection that use more or use less of the information which is available or might be made available for selecting. The difference is in degree more than in kind. Too often the old method is condemned because it does only what a more careful study and measurement would lead us to expect it to do, whilst a method heralded as new is, on account of its plausibility, extolled far beyond what we really have a right to expect of it.

For further example: if the selection practised were only that of saving bulls from the high-producing cows, what has one a right to expect? That is tantamount to predicting cows' yields from the yields of their paternal grandams, and one would expect such cows to exceed the average of what their generation would have yielded without selection, by an amount approximately equal to one-fourth of that fraction of the variance which is additively genetic, multiplied by the amount by which the paternal grandams' yields actually exceeded the average of their generation. Thus with one-third of the variance genetic and a selection differential of 150 gallons for the paternal grandams one would expect an increase of only about $12\frac{1}{2}$ gallons in the granddaughters. This might naturally seem almost no increase at all to those who had been led by innuendo to think that they had a right to expect in the granddaughters an increase almost equal to the selection differential practised on the grandams.

These calculations are crude and sketchy and do not include, for example, what may be expected when selection is practised simultaneously on dams and sires, grandams and grandsires, but naturally with varying intensities on each, and with varying degrees of knowledge about each. These illustrations have been used to show what kinds of knowledge are needed, and how one should proceed to make a business-like estimate of the probable gains to be derived from various methods of selection, progeny-testing, &c. Not until such a valid estimate is made, is one in a position to decide whether a given procedure is likely to provide gains that will more than offset its costs. In preparing these estimates, there is work in plenty to be done in measuring reproductive rates, selection differentials reasonably attainable, the genetic portion of the observed variance, &c.

In addition to the genetic variance that can be expressed by an additive scheme, there is a portion (perhaps a very large portion in stocks that are already improved) of the variance which is genetic in a broad sense, but cannot be expressed additively because the gene combinations interact in other ways. Such gene interactions include inhibitory, multiplicative, complementary and epistatic effects, and also what may be a very

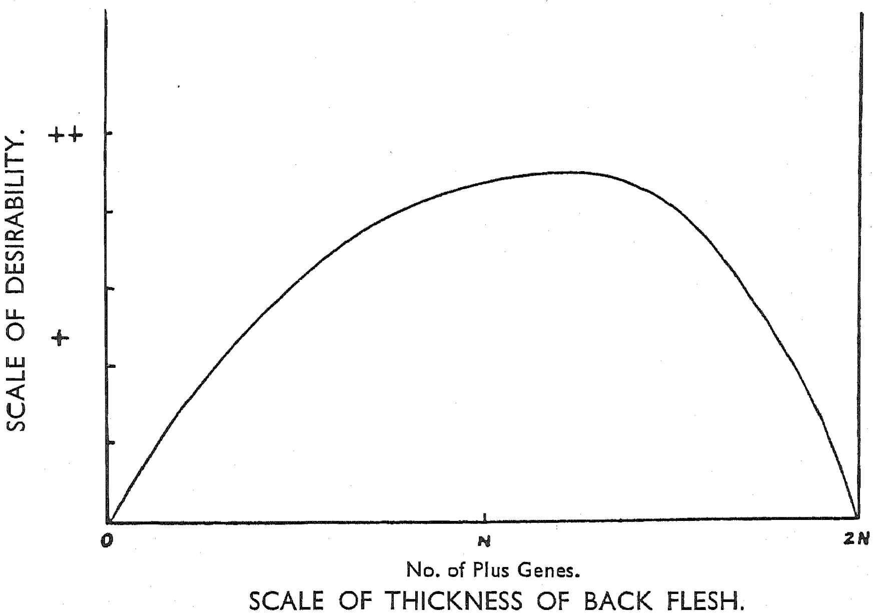

Diagram illustrating the case where the maximum of desirability may be produced by an intermediate combination of genes. In such a case selection usually produces noticeable results in the first few generations it is practised, but rather quickly approaches a limit beyond which progress is not made, although hereditary variability still remains. Further progress can often be made if some combination of inbreeding and outbreeding is practised along with continued selection.

common class of cases where that which is optimum in the breeder's opinion is genetically intermediate. For instance, in bacon swine too thick a back is as undesirable as a back too thin. Hence, although the genes affecting thickness of back might perhaps act additively in terms of linear measurements to make the back thicker or thinner, yet they would not act additively when measured on the scale of how much more or less desirable they make the bacon carcase. That is illustrated schematically in the accompanying diagram. Another example, outwardly different but the same in principle, may be furnished by dressing per cent. in swine. Other things being equal, the higher the dressing per cent. the more desirable the pig from the butcher's viewpoint. From the grower's standpoint there must be some limit to this. The pig must have a certain weight and volume of digestive and other vital organs if it is to be healthy and thrifty. Hence, considering everything, the ideal pig

in this respect will be something of a compromise between two partially irreconcilable ideas, having a dressing per cent. somewhat lower than the butcher wishes but somewhat higher than the grower would wish if he could afford to disregard the butcher's desires. It is characteristic of such cases that the individual genes cannot be rated as either good or bad, since the directions of their effects are so dependent upon the combination of other genes present. Hence selection is for or against gene combinations as such, rather than for or against the constituent genes of those combinations. On the other hand, the mechanism of inheritance is such that the genes and not the gene combinations are the units of inheritance.

The problem presented by such variance can be solved by the use of inbreeding to differentiate the stock into genetically distinct strains or families, with rare outcrosses between such families to restore the variance and make new combinations possible. Such a differentiation into lines should permit inter-family selection, which would be more effective than individual selection. However, the proper balance to be maintained between the intensity of inbreeding, frequency of outcrossing, and intensity of individual and family selections, in order to promote the maximum rate of progress, offers a whole series of problems, the complete solution of which may well vary from case to case and require continued research for years to come on a scale not yet approached in any country.

In summary, then, we are agreed that inheritance is complex, and that each trait must be studied for itself from several points of view. We are also agreed that the first practical step in breeding is selection under an environment which will permit the genetic differences between individuals to manifest themselves as definitely as possible. We are agreed that progeny tests and, at least, a little initial attention to pedigree are quite helpful. We are not agreed as to the relative amounts of attention that should be given to individual performance, pedigree, and progeny test. We are agreed that it is desirable (as Mr. Smith especially has emphasized) to control environment as much as possible, so as not to be misled by it when making selections, but we differ in our optimism as to how complete control can be in actual practice. We are not entirely agreed as to the gains that will accrue from a complete and detailed knowledge of the technical genetic situation in each case. We are far from agreeing on the importance which inbreeding and outcrossing should receive in breeding for productivity.

I hope that such discussion as this, which of itself solves no problems, may nevertheless contribute to their solution by formulating them more clearly, and particularly by presenting to our colleagues in more classical branches of biology some view of the nature and complexity of the problems that are still unanswered. Measurement looms large in such problems. This explains the importance of quantitative methods in applied genetics.

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THE EFFECT OF SHADE ON AMERICAN COTTON

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LARGE tracts in the south-western Sudan and in Uganda give but poor yields when cotton is introduced as a crop, yet examination of these areas shows nothing in the way of rainfall, soil, or pests which is likely to be a decisive factor in crop-production. A notable characteristic of these regions, however, is the prevalence of long periods when the sky is more or less heavily overcast. It was suggested that the depressed yields obtaining in such areas might be attributable to the high proportion of overcast days during the growing-season. Canney [1], in writing of the climatic limits of rain-grown cotton, points out that '. . . *abundant sunshine* has not yet received sufficient attention, and it does not appear that the limit of cloudiness beyond which cotton growing is hazardous has ever been defined. The muggy weather and even cold humid conditions, which are associated with the excessive cloudiness of large areas in the Tropics, are fatal to the production of good quality cotton.'

It was manifestly impossible to test the effect of cloudiness in the districts in question, and an experiment was designed and carried out during two successive years at Shambat,[1] by the writer, to see whether an artificial cloud-effect produced a marked depression in the yield.

The results of this experiment, though they provide a strong indication that cloudiness greatly depresses yield, are not susceptible of statistical treatment, but the differences obtained are nevertheless of such magnitude as to carry conviction.

The investigation of the effect of shade presents great practical difficulties because any experiment designed on a sound statistical basis, would, of necessity, be extremely cumbersome. Also, under irrigation conditions, the point at once arises, whether shaded areas are to be watered as frequently and as heavily as unshaded areas. In the first year's experiment, watering was the same for both areas, as it was felt that this gave a more 'muggy' atmosphere under the shade, which would more nearly approach the humid conditions associated with overcast areas. In the second year there were three treatments; a 'Medium Shade' (comparable with the first season's shade), a 'Heavy Shade', and a 'No Shade' area. These areas were all watered at the same intervals, but a differential watering was given, the Heavy Shade receiving least.

In the 1931–2 experiment an area of 20×8 m. was shaded by a roof of *damour*[2] cloth, stretched at a height of five feet above the cotton ridges, with the main length running east and west, and sloping 'eaves' of cloth along the ends. This area, together with a corresponding unshaded area, both adequately belted, was then sown with 'Delrect II' cotton (a Delta-

[1] Shambat is in the northern Sudan, in the immediate vicinity of Khartoum. All crops there, including cotton, are grown entirely under irrigation.

[2] *Damour* is a coarse, white, cotton cloth.

Webber selection), at a spacing of 90 cm. between the ridges and 45 cm. between the 'holes' (each containing two plants).

The 1932–3 experiment was of similar design, except that there were three areas: a Medium Shade, comparable with that of the previous year, and produced by a roof of the same *damour* material; a Heavy Shade, consisting of two layers of hessian; and a No Shade area. The hessian used for this purpose was of rather open weave, and even when it was doubled, the sun could be seen through it and the plants under it were lightly flecked with sunlight. The gross area of each shade was $20 \times 5{\cdot}5$ m. with the length running from east to west and sloping eaves at the ends.

The soil was very regular, and the spacing and variety used were the same in both years.

In 1931–2, four shedding-troughs of the type described by Bailey and Trought [2] were placed in position five weeks after sowing; two under the shade and two in the outer area. Each trough was designed to catch half the sheddings from twelve pairs of plants, but observations indicated that the troughs collected rather more than half. Daily flower-counts were made throughout the season on the plants that had been provided with these troughs, and the sheddings were daily collected and classified. In addition, full records were made on a hundred observation plants selected at random, fifty being in the shaded area and fifty outside. Open bolls were picked and recorded daily from the shedding-trough plants, and weekly from the observation 'holes', i.e. on a hundred plants per treatment.

In the following year, shedding-troughs were not employed, but very full records were made on thirty 'holes' in each of the three areas, flower-counts being carried out on both plants in the 'hole' (i.e. on sixty plants per treatment). Each flower was tagged and dated, and a record kept of flowering, plant by plant, throughout the season. Complete plant-diagrams were made fortnightly, and boll-shedding was calculated by deducting the number of bolls present on a plant from the total flowers borne by that plant. Bud-shedding was arrived at by subtracting the number of bolls shed from the total number of blank nodes on the plant.

In both years weekly records were made of height and nodes, and of the total number of leafless nodes on the main stem. In all records the cotyledonary node was taken as '0'.

The effect of shade on growth.—Fig. 1 shows the growth-rate, node-development rate, and leaf-fall in all the experimental areas for both seasons. In neither year did the *damour* shade (Medium Shade) have an appreciable effect on height till after the first seven weeks from sowing, but nineteen weeks after sowing, the 1931–2 shaded plants averaged 25 cm. more than the unshaded, whilst the 1932–3 Medium Shade plants were, on an average, about 7 cm. taller than the No Shade by October 31 (eleven weeks after sowing), and this difference remained fairly constant till the end of the season.

In the first season the *damour* plants were taller than the unshaded plants and produced more nodes; in the succeeding year they were taller

than the others (though not so pronouncedly) but produced fewer nodes. In both cases, however, the internodes of the shaded plants were longer.

The Heavy Shade (double hessian) was tried only in the second season, but the effect on height was very marked (Fig. 1 (*a*)). Both height and number of nodes were much reduced and the internodes (especially those produced later in the season) were shorter, bringing the height and node curves closer and closer together as the season advanced.

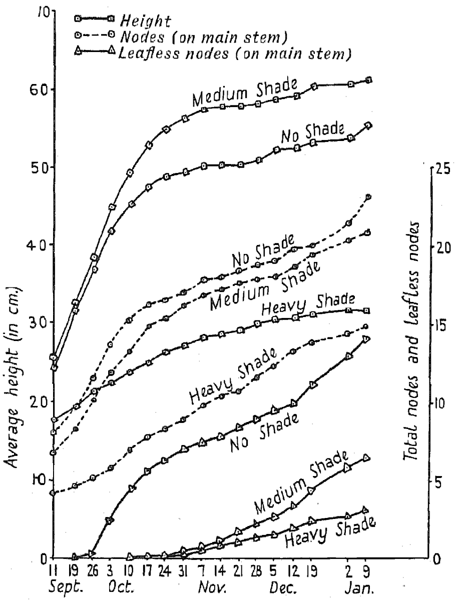

FIG. 1 (*a*). Growth, node-development, and leaf-fall in 1932–3. Sowing date August 14.

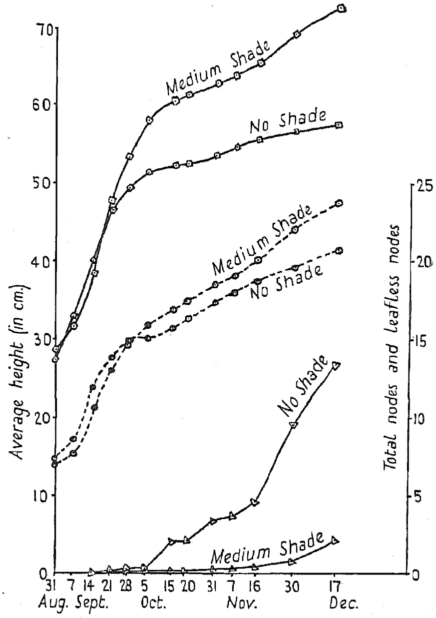

FIG. 1 (*b*). Growth, node-development, and leaf-fall in 1931–2. Sowing date July 31.

Effect on leaf-shedding.—The shedding of primary leaves is very considerably reduced by shading with *damour* and still further reduced under a heavy shade. These effects are clearly shown in Fig. 1 (*a*) and 1 (*b*).

Effect on position of lowest sympodium (*fruit-bearing branch*).—Shading was found to delay the production of sympodial fruiting branches. The delay was definite, but very slight, when medium shade was given, but with heavy shading the effect was very marked indeed. In 1932–3 only nine out of the thirty recorded plants had produced any sympodia at all in the heavy-shaded area, after the elapse of twenty weeks from the time of sowing, and all these nine were situated near to the edge of the shaded area, where they received rather more light. The unshaded, but otherwise comparable, plants in that year had produced eighteen fruiting branches in the same interval of time. The 'delay' was, in all cases, due to the suppression of those lower buds on the main stem which would otherwise have given rise to sympodial branches.

Effect on structure of stem and root.—The average diameters of root, hypocotyl, and stem of the Medium Shade plants were almost identical with those of the No Shade. Under the Heavy Shade, however, root-diameters were reduced to from a quarter to a third of the normal, hypocotyls to from a half to a third, and stems to half size. The depth of rooting also was reduced under the Heavy Shade.

The No Shade stems showed a gross xylem area in cross-section of about 60 per cent. as against 50 per cent. for the Medium Shade and 20 per cent. for the Heavy Shade. This was rather to be expected as a result of the reduced water-strain under shade conditions.

The No Shade roots, however, showed a very slightly smaller gross xylem area in cross-section than the Medium Shade, which again was slightly less than the Heavy Shade. To offset this, there was a greater degree of lignification in the No Shade and Medium Shade sections as compared with the Heavy Shade.

These results agree for the most part with the work of Penfound [4].

Effect on numbers of fruiting branches and fruiting nodes.[1]—The Heavy Shade made a tremendous difference to the plants. Under it there was an almost complete suppression of fruiting branches and consequently of fruiting nodes; even where sympodia were produced, they rarely exceeded 0·5 cm. in length and carried only minute buds.

In the first season rather more fruiting branches were produced per plant under the Medium Shade than in the No Shade area, but the reverse obtained in the second season.

As can be seen from the 1932–3 results (Fig. 2), the unshaded plants produced far more 'fruiting nodes' than the Medium Shade plants (63·4 per plant as against 44·1). This outstanding difference was due to the fruiting branches on the unshaded plants being longer and having more nodes than those of the shaded plants—a fact observed in both seasons.

This marked difference in fruiting-node production between the two treatments is somewhat discounted by the larger number of 'blank' nodes (i.e. nodes from which the buds, flowers, or bolls have shed) on the unshaded plants. In Fig. 2 the difference in height between the blank-node and fruiting-node curves shows the number of nodes on the plant actually bearing either buds or bolls at any particular time, i.e. it is equal to the height of the boll curve plus that of the bud curve. It will be seen that, despite the increased number of blank nodes on the sympodia in the No Shade area, the total production of fruiting nodes was such that the unshaded plants still produced almost exactly twice as many bolls as the Medium Shade plants.

Effect of shade on shedding, flowering, and boll-production (Figs. 3 and 4).—An examination of Fig. 3 indicates that very considerably less bud-shedding and boll-shedding took place in the case of shaded plants. This would have led to the production of a larger crop from these plants, had not the total production of buds been very much reduced on those plants which were shaded, the net result being a marked depression in flower- and boll-production (Fig. 4).

[1] The term 'fruiting nodes' is used throughout this paper to mean all nodes, either on primary or secondary sympodia, which bear, or have borne, a bud, flower, or boll.

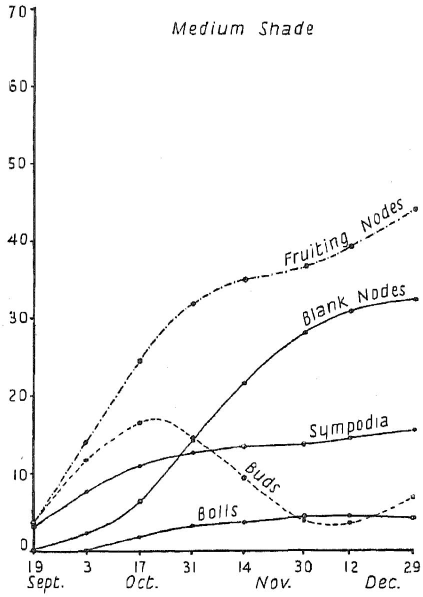

FIG. 2 (*a*). Medium Shade. Fruiting nodes, blank nodes, sympodia, buds, and bolls graphed as average totals per plant per fortnight 1932–3. Sowing date August 14.

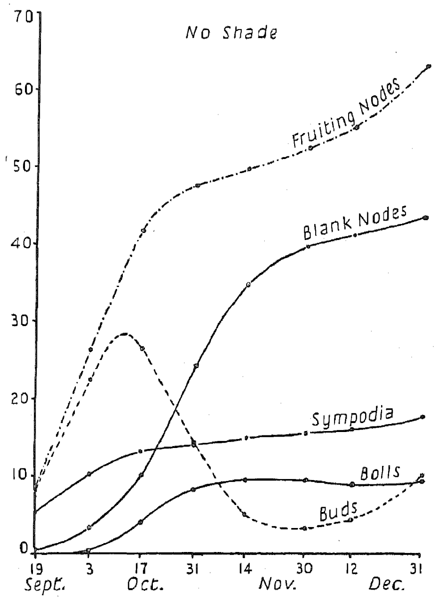

FIG. 2 (*b*). No Shade. Fruiting nodes, blank nodes, sympodia, buds, and bolls graphed as average totals per plant per fortnight 1932–3. Sowing date August 14.

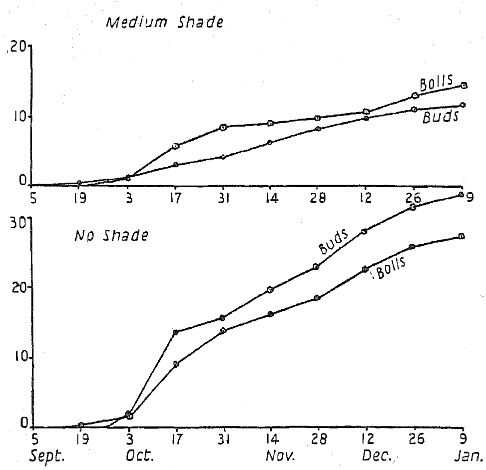

FIG. 3 (*a*). Bud- and boll-shedding 1931–2. Cumulative averages per plant. (Figures from shedding-troughs.)

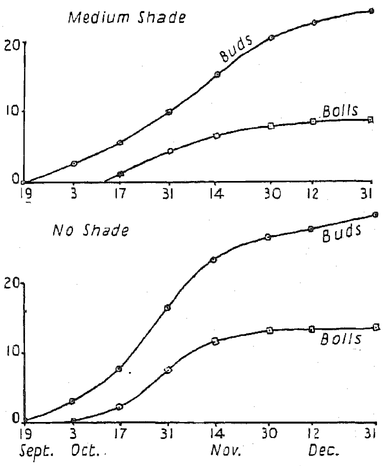

FIG. 3 (*b*). Bud- and boll-shedding 1932–3. Cumulative averages per plant. (Figures from plant-diagrams.)

This reduction of buds was so intense under the Heavy Shade in 1932–3 that the plants subjected to this treatment produced an average total of only 1·57 buds each during the season, and of these 0·70 was shed. This figure of 1·57 compares with 63·40 and 44·10 for the No Shade and Medium Shade areas respectively. Furthermore, the development of such buds as were produced was so hampered by the Heavy Shade that no flowers were ever formed.

The daily collections made with the shedding-troughs in 1931–2 show (Fig. 3 (*a*)) a very much higher rate both of bud-shedding and boll-shedding under unshaded conditions than under the Medium Shade,

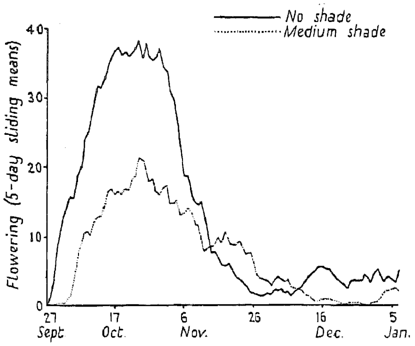

FIG. 4 (*a*). Flowering curve, 1932–3, of 60 plants per treatment. Sowing date August 14.

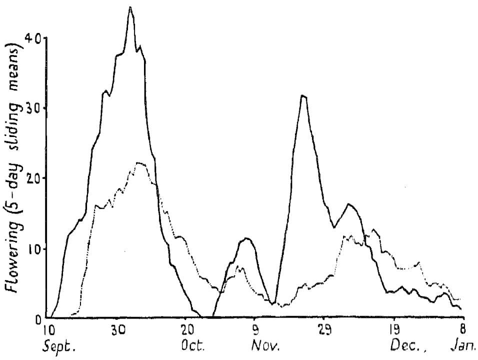

FIG. 4 (*b*). Flowering curve, 1931–3, of 48 plants per treatment. Sowing date July 31.

and thus corroborate the figures obtained from plant-diagrams in the succeeding season (Fig. 3 (*b*)). The trough-system, however, does not give an accurate basis for calculating the shedding per plant; it is designed more as a means of obtaining a sample of the sheddings for classification into size-groups and for pest-investigation. The actual indications are that buds are shed at an earlier stage of development and bolls tend to remain on a little longer under shade conditions.

Effect of shade on final yield.—As can be seen from the following table, shading produced a very striking reduction in yield:

	Total yield (lb.)		*Mean yield per observation hole (gm.)*	
	1931–2	*1932–3*	*1931–2*	*1932–3*
No Shade . .	27·0	20·8	59·8±2·3 s.e.	48·0±2·6 s.e.
Medium Shade .	10·3	7·2	28·7±0·9 s.e.	14·7±1·2 s.e.
Heavy Shade . .	..	0·0	..	0·0

Effect on maturation-period of bolls.—In 1932–3 the average maturation-period for healthy bolls under the Medium Shade was 52·6 days as against 54·7 days for the No Shade. So few healthy bolls, however, reached maturity under the shade that the above figures are of rather doubtful value.

Pests and diseases.—The markedly reduced yield of the Medium Shade

cotton in both seasons was not *directly* or entirely due to lack of sunshine, it was partly brought about by a severe boll-worm attack (mostly *Diparopsis*, the Sudan boll-worm, in 1931–2, and *Diparopsis* and *Platyedra* equally in 1932–3). Of the total bolls produced in 1931–2, 53 per cent. were diseased in more than two loculi in the No Shade, and 78 per cent. in the shaded area. In the following season the respective figures were 48 per cent. and 77 per cent. The vast majority of these diseased bolls were infected with boll-worm and the additional severity of the boll-worm attack in the Medium Shade was almost certainly due to the removal of the inhibiting effect of sunshine on the pest.

In 1932–3 the bolls produced on observation 'holes' were grouped as follows for severity of disease:

	Boll-production (hole averages) Medium Shade	No Shade
Completely healthy	0·37	4·27
Diseased in 1–2 loculi	1·33	4·70
Diseased in >2 loculi	5·63	8·27
Total bolls	7·33	17·24

In the first season, jassids did decidedly more damage under shade than they did outside, whilst thrips and flea-beetle were also somewhat more numerous. Shading also increased Red Leaf Spot—a rather common disease in the Sudan, caused by *Macrophomina phaseoli*.

In the second season, jassids did most damage in the Heavy Shade; they did a certain amount of damage in the Medium Shade, and were negligible in the No Shade. Flea-beetles were most numerous in the unshaded portion and least numerous in the Heavy Shade.

'Blackarm' was moderately severe in the early part of the 1932–3 season. The Heavy Shade showed 1·5 leaves infected per plant on an average, by October 11, 1932; the Medium Shade had 2·2, and the No Shade 16·1 (these figures include infected leaves which had shed by this date). This marked difference was probably to some extent due to plants under the shades being sheltered from direct rain.

Unpublished work[1] at Shambat corroborates these figures to some extent. Cotton was grown in pots in the open and these were then placed in the Heavy, Medium, and No Shade areas and sprayed with *B. malvacearum* culture. The resultant degree of infection was similar in the No Shade and Medium Shade areas, but there was a great reduction in the number of lesions under the Heavy Shade. This indicates that the comparative freedom from blackarm is not due entirely to shelter from direct rain splash or to a growth-effect caused by shading, for, in the case in point, the plants were grown in the open and only brought under the shades for spraying and incubation of the disease. This resistance to blackarm may be mechanical, due to the partial closing of stomata under shade conditions.

At the end of each season the plots were cut back in order to obtain fresh young growth for observation on 'Leaf Curl'. In the first year, the Medium Shade showed more leaf curl than the No Shade, whereas in

[1] By Mr. T. W. Clouston, Plant Pathologist, Sudan Government.

the second season there was most leaf curl on the unshaded plants and least on the Heavy Shade plants, the Medium Shade being intermediate. In both seasons the actual symptoms were more severe on the shaded plants.

Effect on 'nep'.—Samples of cotton from both areas of the first season's experiment, on being tested, showed only a low percentage of immature hairs; of the two, the shaded cotton, if anything, was the less neppy. These tests were carried out *on healthy cotton only*; probably the higher percentage of boll-worm bolls in the shaded area would tend to bring up the number of immature hairs to some extent in a normal commercial sample.

Effect on length of lint.—The Medium Shade and No Shade areas were each sampled by taking three healthy sub-basal seeds from each observation 'hole', i.e. ninety seeds per treatment. These seeds were combed and measured on the system described by Bailey [3]. The No Shade lint was $34{\cdot}2 \pm 0{\cdot}5$ mm. long, whereas the Medium Shade lint was $36{\cdot}2 \pm 0{\cdot}3$ mm. This difference was shown statistically to be decidedly not due to chance, but, owing to the lack of replication, it is impossible to state definitely that it was due to treatment and not to soil. The soil did, however, appear to be very uniform over the whole experiment.

Conclusion.—After making due allowance for differences in diseases and pests, the results obtained in both seasons show clearly that partial shading (and hence, presumably, any prolonged heavy cloud-effect) greatly reduces the yield of cotton, largely by a direct effect on the growth of the plants, though partly through an increased pest-incidence. The extreme (which admittedly was in no way comparable with any cloud-effect) was shown by the complete absence of crop, and even of flowers, under a dense shade.

Though a *damour* shade of the type used in these experiments is not strictly comparable with a heavy and prolonged cloud-effect, there must be a good deal of similarity in the reaction of cotton to shade, whether natural or artificial, so that cotton-growing in any dull, overcast area would probably be distinctly hazardous.

Summary

The experiments were designed as a preliminary investigation to determine, by means of artificial shades, the effect of continual clouds on American cotton. In the first year's work an area shaded with coarse, white, cotton cloth is compared with an equal, unshaded area. The second year's experiment deals with a triple comparison between a shade similar to the previous year's, a heavier shade composed of a double thickness of hessian, and an equal unshaded portion.

Shading with cotton cloth reduced the production of buds, flowers, and bolls, and also the shedding of these and of leaves. The incidence of blackarm was lessened. Yield was reduced by nearly two-thirds. Plant-height was increased and also the height of the first sympodium, and the lint produced was longer. Pest-incidence (boll-worm, aphis, and jassid) was increased.

Under the double hessian shade, bud-production was very much

further reduced and flowering and bolling completely prevented. The development of buds in the lower region of the main stem was suppressed, so that the lowest sympodia were produced very high up the stem. Sympodia were extremely short, and there was a large reduction in plant-height and in the number of main-stem nodes. Leaf-shedding was greatly lessened and so was the incidence of blackarm. Diameters of stem and root were smaller, as was also the proportion of xylem to the other tissues in the stem. The roots were less lignified and rooting was not as deep as in the other treatments.

The conclusion is drawn that continued cloudiness may be a major factor in lowering the yield of cotton.

Acknowledgements

The writer desires to express his indebtedness to Mr. M. A. Bailey, Controller of Agricultural Research, Sudan Government, Mr. T. Trought, Chief Plant Breeder, Sudan Government, and Mr. H. E. King, Plant Breeder, Sudan Government, for the advice and help they have given; also to various members of the *effendia* staff of the Plant Breeding Section for carrying out much of the field-observation work.

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ADDENDUM: THE DIAGRAMMATIC INTEGRATION OF PLANT-DIAGRAMS

Fig. 5 gives a diagrammatic representation of the plant-structure in the three areas in 1932–3.

Diagrams (*a*), (*b*), and (*c*) show the total production of buds along primary sympodia up to the end of November and, superimposed, the distribution of bolls present on the plant at that time. To obtain these bud-production diagrams, the length in nodes of the lowest sympodium was averaged for the thirty recorded plants in each area, subsequent sympodia being treated similarly. Next, every nodal position along each sympodium was averaged separately. In the diagrams the positions between the dotted line, which intersects the sympodia, and the main stem represent the *average* lengths of sympodia in nodes, any nodes in excess of this amount being outside the dotted lines. The rectangles represent, by their area, the average bud-production at each nodal position along the sympodium. For example: suppose there are three plants having lowest sympodia of 1, 2, and 3 nodes in length respectively, then this would be represented by a horizontal line three nodes in length (the extreme) intersected by a dotted line at two nodes from the main stem (the average). The first node would bear a square of unit size as all the plants bear a node, and hence have produced a bud, in this position; the second node would bear a rectangle of two-thirds unity, as two out of the three plants have a node in this position (and, hence, either

bear or have borne a bud there), and the third node would bear a rectangle of one-third unity which would be beyond the dotted line denoting the sympodial averages.

On this system sympodia are averaged according to their *relative* position, and not according to their absolute position as determined by the node-numbers of the axils whence they sprang, i.e. all first sympodia are averaged, followed by all second and so on, *not* all sympodia at, say, the fifth node followed by those at node 6, &c.

The length of the vertical line below the lowest sympodium shows the average

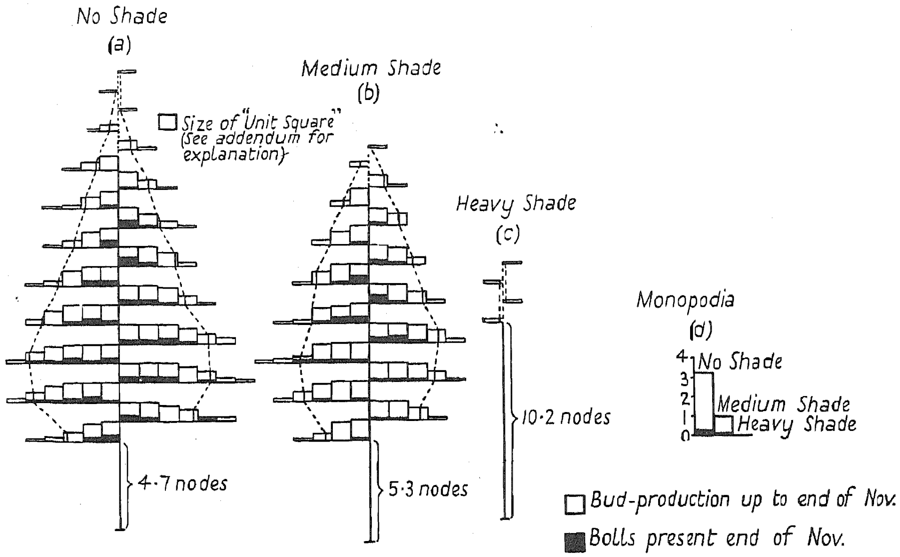

FIG. 5 (*a*), (*b*), and (*c*). Bud-production up to end of November (approx. to end of primary growth) and, superimposed in black, the distribution of bolls present at that time.

FIG. 5 (*d*) shows the total monopodial production of fruiting buds and also the number of monopodial bolls present superimposed in black.

All figures are averages of 30 recorded plants per treatment.

'height' in nodes of the latter, whereas the solid vertical line above the first sympodium shows the average number of sympodia per plant.

The height of the first sympodium in the 'heavy shade' diagram (*c*) is really a minimum height as, in this treatment, only some of the plants had produced sympodia on the dates indicated on the diagrams. Plants that had not produced a sympodium were not neglected; their total main-stem nodes were added to the general figure in obtaining the average height of the first sympodium.

The superimposed blacked-in areas show the distribution on the plant of bolls present at the end of November. The method of obtaining these diagrams is practically identical with that described above for bud-production, except in so far as these diagrams are of bolls *present* on a definite date and not of boll-*production*. These black rectangles show, by their area, the average 'boll value' of each nodal position along each sympodium. No attempt has been made to indicate mean sympodial lengths, as such figures would be meaningless for bolls.

Fig. 5 (*d*) shows the bud-production on monopodia and the number of monopodial bolls present at the end of November in all treatments. The same scale for unity is adopted as for Figs. (*a*–*c*).

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FIELD EXPERIMENTS ON THE ACTION OF CALCIUM CYANAMIDE ON GERMINATING SEEDS AND ON CHARLOCK IN BARLEY

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IN earlier papers [1, 2, 3, 4] in the *Journal of Agricultural Science*, Crowther, Richardson, and Mukerji have presented the results of laboratory and pot-culture investigations on the decomposition of calcium cyanamide ($CaCN_2$) in relation to its use as a fertilizer. It was shown that in normal moist soils the decomposition through free cyanamide and urea to ammonia was completed in a few days. In spite of this rapid decomposition, the free cyanamide sometimes proved highly toxic to plants and certain micro-organisms. Thus, nitrification of the ammonia from calcium cyanamide used in pot cultures was retarded, in some soils for a few days, in others for several weeks. Again, germination experiments under controlled laboratory conditions showed serious damage to seeds directly treated with calcium cyanamide, although the danger of injury disappeared in a few days with the disappearance of the cyanamide from the soil.

The laboratory work on calcium cyanamide was accompanied by field experiments on the practical application of the fertilizer. The results of the experiments on grassland have already been described [5]; the present paper deals with the action, in the field, of calcium cyanamide on germinating seeds and on charlock in barley; in a subsequent paper [6] the fertilizing value of calcium cyanamide will be compared with that of other nitrogenous manures, at a number of centres in different parts of Britain.

In reporting the field experiments in this and the following paper, commercial calcium cyanamide is described, for brevity and in accordance with common practice, simply as 'cyanamide'.

Field Germination Experiments

In the laboratory experiments on germination, described in the first paper of this series [1], it was shown that the toxic action was due to the cyanamide itself, not to its decomposition products, and that the degree of damage depended on the amount of cyanamide present in the soil during the 24 hours after the seeds were sown. Conditions, such as higher temperature, which hastened the disappearance of the cyanamide, reduced the damage. In these experiments very heavy doses were used.

In the series of pot experiments reported in a later paper [4] cyanamide was mixed with the soil on the day of sowing the seed, but there were no bad effects on germination, except on one soil from which cyanamide disappeared particularly slowly. In these pot experiments, the fertilizers were incorporated with the soil much more evenly than is possible in the field.

Field germination experiments were conducted on Rothamsted soil with a number of crops at different seasons, using a wide range of rates of application and varying time intervals before or after sowing the seed. The experiments were carried out in 1926 by R. B. Dawson [7], in 1927 by the late A. J. Walker, and in 1929 by H. L. Richardson.

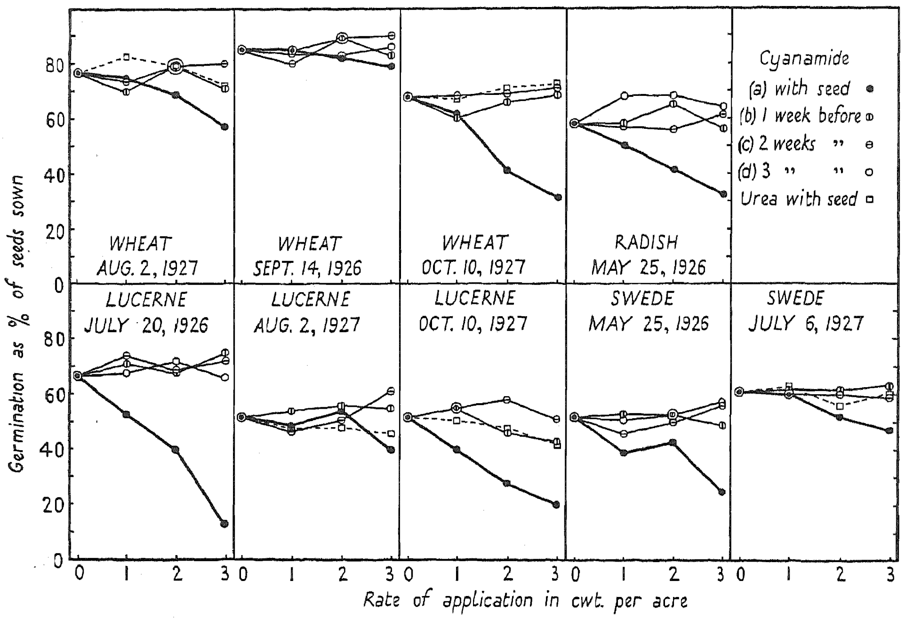

FIG. 1. Percentage germination of wheat, radishes, lucerne, and swedes in field experiments with increasing rates of application of cyanamide at different intervals before sowing. The date of sowing the seeds is given for each experiment.

Details of the experiments varied in different years, but the general procedure was similar throughout: a seed-bed was prepared under a wire cage and the treatments were applied to strips containing a definite number—one or two hundred—of evenly sown seeds; treatments were duplicated in adjacent blocks, within which a random arrangement was secured. The cyanamide was mixed with sand to facilitate even application, and, unless otherwise noted, it was well raked or forked into the surface-soil. The number of germinated seedlings above the soil was counted at frequent intervals until the numbers were constant or decreasing; the maximum values were taken for discussion. As the general form of the germination curves was similar to that in the laboratory experiments ([1], Fig. 2), they are not reproduced here. Where cyanamide had any effect on final numbers, it also retarded germination.

The results obtained in the 1926–7 experiments are summarized in Fig. 1. The degree of variation was such that only well-marked effects could be considered real, and none of the treatments, except certain applications of cyanamide with the seed, had a definitely adverse effect on germination. That is to say, on Rothamsted soil the application of cyanamide in doses up to 3 cwt. per acre, one week or more before

sowing, was not injurious with any crop at any season. As in the laboratory experiments, urea, applied with the seed in doses up to 3 cwt. per acre, had no appreciable effect.

When cyanamide was applied on the day of sowing the seed, the heaviest dose (3 cwt. per acre) caused appreciable injury in every trial but one (namely, wheat in September); the intermediate dressing (2 cwt. per acre) was definitely injurious in about two-thirds of the trials; the smallest application (1 cwt. per acre) produced no appreciable injury in more than half of the trials, whilst in none did it reduce germination by more than one-quarter. Wheat was unaffected by the dressing of 1 cwt. per acre applied with the seed at any season.

In order to examine the influence of seasonal factors on the amount of injury when cyanamide was applied with the seed, the following data were chosen: (*a*) average soil temperature at 4 in. at 9 a.m., over the week beginning with the day the seed was sown, (*b*) total rainfall over 48 hours from 9 a.m. on the day of application, which would indicate whether the cyanamide might be washed into the soil or leached away from the seeds (see Table 1).

TABLE 1. *Meteorological Summary. Field Germination Experiments*

Crop	*Date of sowing seed and applying treatment*	*Soil temperature average for week*	*Rainfall, 48 hours' total*
		°F.	inches
Swede and radish	May 25, 1926	60·0	0·013
Swede	July 6, 1927	64·8	1·396
Lucerne	July 20, 1926	61·4	0·154
Wheat and lucerne	Aug. 2, 1927	63·4	0·000
Wheat	Sept. 14, 1926	61·0	0·002
Wheat and lucerne	Oct. 10, 1927	49·0	0·011

The lower temperature of the October treatments was accompanied by heavier injury, with both wheat and lucerne, than in September or August. This agrees with the laboratory experiments, and suggests that greater care is required in using cyanamide when the soil temperature is low. In July severe injury occurred with lucerne, which is difficult to explain except on the assumption that the light rain which fell brought the cyanamide into intimate contact with the seeds. Rather heavy rain followed the swede experiment in July, while the temperature was little above that in the May experiment; the amount of injury was much less in July even with the 3 cwt. dressing, and this suggests that the heavy rain had washed the cyanamide down away from the seeds. Moisture determinations made on the soil at the time of application did not show any clear relationship with the amount of injury: in the laboratory experiments also, moderate differences in soil moisture had much less effect on toxicity than had differences in temperature.

It is not possible to decide from these experiments whether one crop was more sensitive than another to cyanamide, because of the differences in the times at which they were tested and in the natural germination of the seeds. On the whole, wheat seems to have been least affected.

With many crops, notably spring cereals, it becomes important to sow the seed during the first period of suitable weather and a week's interval between applying a fertilizer and sowing seed may be impracticable. The laboratory work showed that cyanamide disappeared so rapidly from most soils that the interval might safely be reduced to two days, except for the heaviest applications in cold weather. In the results recorded above, application even on the day of sowing was not very harmful when the dressing was small. It has also been suggested elsewhere that the damage might be reduced by applying the cyanamide a few days after sowing, on the hypothesis that the seed would pass through the most susceptible stage without coming into contact with cyanamide.

These questions were examined in the spring of 1929 on barley, for which they are especially important. A dressing of 2 cwt. per acre was applied 7, 2, and 0 days before the seed and 2 and 7 days after sowing. With the three treatments at or after sowing, the effects of leaving the cyanamide on the surface and of raking it in were compared; a part of the experiment was repeated at a week's interval to allow for possible weather changes. Actually, there was no appreciable rainfall shortly following any of the applications of cyanamide, whilst the average soil temperatures were similar after each sowing (44·5 and 45·9° F.).

TABLE 2. *Influence of Cyanamide on Germination of Barley (Germination as per cent. of seeds sown)*

Date of sowing	*No cyanamide*	*Seven days before raked in*	*Two days before raked in*	*With seed*		*Two days after*		*Seven days after*	
				Raked in	*Left on surface*	*Raked in*	*Left on surface*	*Raked in*	*Left on surface*
March 23	81	. .	. .	80	76	81	82	81	80
March 30	82	85	84	81	85	80	75	85	76
Mean	82	85	84	80	80	80	78	83	78

It was found (Table 2) that, even with the 2 cwt. per acre dressing and low temperature, the application of cyanamide with the seed had no appreciable effect on germination. This was true also for applications shortly before or after sowing, and it may be concluded that barley is resistant to the toxic action of cyanamide, and that applications on the day of sowing the seed are safe in ordinary field practice provided that the soil is harrowed between adding cyanamide and sowing the seeds. This is supported by actual experience in replicated field experiments on the effect of fertilizers on yield of barley, where observations of germination showed no damage from cyanamide applied on the day of sowing or a few days earlier.

As sugar-beet is believed to be especially sensitive to injury from cyanamide, tests were made in 1929 with dressings of cyanamide up to 4 cwt. per acre, applied 2 days after sowing the seed. (This time of application has been recommended abroad.) The effects of leaving the treatment on the surface and of raking it in were compared. Instead of simple replication, the experiment was repeated four times on different blocks at weekly intervals, from April 17 to May 9.

TABLE 3. *Influence of Cyanamide on Germination of Sugar-beet (Cyanamide applied two days after sowing seed)*

Rate of application	*Germination as per cent. of 'seeds' sown, mean of 4 sowing times*		*Date of sowing seed*	*Germination as per cent. of 'seeds' sown, mean of 6 cyanamide plots*	*Temperature (mean for week after sowing)*	*Rainfall (48 hours after application)*
cwt./acre	Unraked	Raked			°F.	inches
0	150	153	April 17	112	45·3	0·00
1	148	139	April 23	120	44·5	0·00
2	147	132	May 1	138	45·9	0·32
4	106	100	May 9	146	49·8	0·35
	Standard error 11·1			Standard error 9·1		

Because of the variable numbers of true seed contained by the sugar-beet 'seed' as sown, the standard errors were rather high, and only well-marked differences were significant. The 4 cwt. dressing was the only one that significantly lowered germination, in either raked or unraked soil or both together, although it was evident to the eye that the lighter applications had somewhat retarded growth. Raking seemed to have a bad effect with each rate of application, but neither the individual differences nor their total were significant.

Although the different dates of sowing refer to different blocks, the untreated plots on the various blocks did not show significant differences. As it is not likely that the soil of the closely adjacent blocks varied greatly in its power to decompose cyanamide, an attempt may be made to relate the germination on different dates to the weather conditions.

The soil-temperature range throughout the experiment was small, and the two April applications were not closely followed by rain, whereas the two May treatments were followed by fairly heavy showers. If the experiments are grouped accordingly, the average germination of all the treated plots in April was significantly below the average of the treated plots in May. Indeed, in May even 4 cwt. per acre of cyanamide did not significantly lower germination, whereas this dressing practically halved the germination in April. (*April*, no cyanamide, 156 per cent.; 4 cwt. cyanamide, 79 per cent.; *May*, no cyanamide, 146 per cent.; 4 cwt. cyanamide, 127 per cent.) Evidently the rain that fell shortly after the May applications protected the seeds from the action of the cyanamide, presumably by washing it away from them.

Practical Recommendations on Time of Application

Caution is needed in applying the results of these field trials in practice, for they relate only to one soil and to very even distribution and incorporation of cyanamide. Other soils, particularly those acid sands which decompose cyanamide more slowly [1], may need longer intervals.

In general, safe intervals between application and sowing are one week for dressings up to 2 cwt. per acre, and two weeks for larger dressings. These intervals may be reduced to about one-half for fertile soils rich in organic or inorganic colloids. Damage is less likely in warm and unsettled

than in cold dry weather; some cultivation should follow soon after application in order to work the cyanamide into the soil.

The interval may often be further shortened. For moderate dressings on fertile soils, up to 1 cwt. per acre for wheat and up to 2 cwt. per acre for barley may be applied on the day of sowing, provided that the cyanamide is harrowed into the soil before the seed is drilled. For sugar-beet, applications up to 2 cwt. per acre may be given two days after sowing, but the fertilizer should then be left on the surface.

The toxicity of recent applications of cyanamide to germinating seeds is likely to effect some elimination of weeds, and a rotation experiment to test the cumulative effect of cyanamide treatment in conjunction with different methods of cultivation has recently been begun at Rothamsted.

Spring top-dressings of cyanamide on winter cereals had only a transitory harmful effect in the field experiments reported in a later paper [6].

Control of Charlock by Cyanamide and by Other Methods

An experiment on the use of cyanamide for the control of charlock (*Brassica sinapis*) in barley is reported in some detail because it afforded quantitative measurements of weed-competition and a comparison of several methods of control.

A strip of barley heavily infested with charlock was subdivided into 36 plots, each of 1/167 acre, giving sixfold replication in separate blocks of the following treatments:

1. Untreated.
2. Hand-weeded.
3. Cyanamide (oiled), 1½ cwt. per acre.
4. Cyanamide (un-oiled), 1½ cwt. per acre.
5. Kainit (powdered), 6 cwt. per acre.
6. Copper sulphate solution, 5 per cent., 40 gals. per acre.

The materials in treatments 3, 4, and 5 were applied by hand from sprinkler tins, treatment 3 being with the powdered fertilizer normally used in this country and treatment 4 with the form that is especially prepared abroad for weed-control. The solution in treatment 6 was applied from a hand-sprayer.

In order to sample varied weather conditions, duplicate blocks were treated on each of the dates May 20, May 23, and May 27, 1931, on each occasion at 05.30 to 06.30 G.M.T. The central shoots of the barley were 3 to 7 in. high, and the charlock had about 4 true leaves, some 2 in. long, with clusters of unopened flower-buds in the more mature plants. The weather conditions, which profoundly affected the action of the different treatments, were:

May 20, overcast, no dew, no rain during the following 24 hours.

May 23, overcast, no dew, 0·3 in. rain during the afternoon.

May 27, some clouds, becoming sunny, heavy dew, no rain during the following 24 hours.

Observations on the leaves showed that the effect of cyanamide resembled that of copper sulphate rather than that of kainit. With kainit the leaves withered soon after application, the edges being affected first; partially wilted plants rapidly recovered. The action of kainit evidently

depends on plasmolysis and not on direct toxicity. Copper sulphate solution produced within a few hours small dead spots, which steadily increased in size until frequently the whole leaf was destroyed. Some plants slowly recovered, but the young leaves were yellowish and unhealthy. Cyanamide likewise attacked the leaf first at the points where the powder fell; it acted more slowly than copper sulphate solution but also caused considerable damage. Many of the injured plants recovered later and produced fresh green growth. Copper sulphate and cyanamide evidently acted by direct toxicity and not by plasmolysis.

The action on the barley, which in addition to having narrow, vertical leaves is protected by a waxy cuticle, was similar to but much slighter than that on the charlock.

Both plants showed the effects of available nitrogen within 7 to 10 days of the cyanamide applications, and by flowering time the charlock treated with cyanamide was ahead of the untreated charlock.

The brief interval required for a visible response to the cyanamide nitrogen is noteworthy. It supplies further evidence, agreeing with that from the pot-culture [4] and grassland [5] experiments, that cyanamide is to be regarded as a 'quick-acting' rather than as a 'slow-acting' fertilizer.

The yields of barley and charlock were investigated by the sampling technique at the end of June, before the charlock seeds had ripened and while the barley was still green. (Table 4.) Numerous other weeds and some young charlock plants appeared between the times of treatment and harvesting, especially in the plots where most of the charlock had been removed. Hence the figures for weeds do not refer only to charlock, but the actual weights of the other weeds were not great (compare 'hand-weeded' column).

The mean yield of barley was raised significantly by all treatments; the seriousness of the weed-competition is shown by the effect of hand-weeding, which increased the yield by almost 60 per cent.

TABLE 4. *Effect of Treatment on Weight of Barley and Weeds, and on Weed-numbers*

Treatment	1 None	2 Hand-weeded	3 Cyanamide oiled	4 Cyanamide un-oiled	5 Kainit	6 $CuSO_4$ solution
Barley, fresh weight in cwt. per acre (S.E. 6·5)						
Treated, May 20	46·0	65·4	72·8	63·2	55·3	55·8
May 23	41·2	64·0	53·5	67·9	53·4	44·6
May 27	31·1	58·4	38·8	40·7	49·8	55·2
Mean	39·5	62·7	55·1	57·3	53·9	51·9
Weeds, fresh weight in cwt. per acre (S.E. 3·5)						
Treated, May 20	49·4	13·2	72·0	52·7	34·9	13·6
May 23	59·6	12·6	88·1	80·7	42·2	33·9
May 27	60·0	6·1	68·8	65·2	31·8	32·9
Mean	56·5	10·6	76·4	66·0	36·4	26·8
Weeds, numbers in thousands per acre (S.E. 90)						
Treated, May 20	980	230	990	670	620	270
May 23	970	190	780	670	670	670
May 27	890	300	700	760	520	720
Mean	940	240	820	700	600	550
Weeds, mean weight per weed in gms.						
	3·2	3·3	5·6	5·2	3·1	2·7

Although the other treatments did not give such high yields as hand-weeding, none of the differences was significant.

The growth of charlock was not, as might have been expected, greatest where the yield of barley was least. All of the differences between treatment means were significant, placing the treatments in the following order of increasing growth of weeds:

Hand-weeded < copper sulphate solution < kainit < untreated < unoiled cyanamide < oiled cyanamide.

Thus the check received by the charlock on the cyanamide plots was only temporary, and it was later outweighed by the fertilizing effect of the nitrogen. The weed-numbers showed that there had been a definite destruction of weeds with cyanamide, although it was less than with the other treatments. The values of the average weight of a single weed demonstrate the extra growth made by charlock with cyanamide; they also show that copper sulphate was the only treatment that permanently stunted the individual charlock plants. Since oiled cyanamide gave a slightly lower yield of barley, a significantly higher yield of charlock, a greater number of weeds per acre and heavier individual charlock plants than un-oiled cyanamide, it is clear that oiling lowered the efficiency of the cyanamide. The effect on the yield of barley was not great enough, however, for the difference to be of practical importance.

There were some considerable differences in the effects of the treatments applied on different dates, showing the influence of the weather conditions already noted. When rain followed application, the general yield of weeds was significantly higher than on the other days, but dew had no appreciable effect. It was evident to the eye that rain washed the cyanamide off the leaves, and the yield of weeds was significantly greater with cyanamide, but not with other individual treatments, when rain followed. Although dew did not increase the weed-destroying action of the cyanamide, it caused a significant degree of damage to the barley. Copper sulphate was most effective (the charlock yield was significantly lower) in the absence of either rain or dew.

Supplementary observation plots were treated on May 27, later in the day, after the dew had gone. The treatments examined were:

1. Oiled cyanamide, 3 cwt. per acre. 2. Kainit, 3 cwt. per acre.
3. Powdered quicklime, 2 cwt. per acre.
4. Copper sulphate, 5 per cent. solution, 40 gals. per acre.
5. Sulphuric acid, 4 per cent. solution, 40 gals. per acre.
6. Sulphuric acid, 8 per cent. solution, 40 gals. per acre.

The first three treatments gave further information about the mode of action of cyanamide. The heavy (3 cwt. per acre) dressing caused as much apparent damage to charlock as the copper-sulphate spray. The same weight of kainit had little effect, whilst quicklime equivalent to the calcium content of the cyanamide caused practically no damage to the charlock leaves. Calcium cyanamide does not therefore act by plasmolysis or through the 'caustic' action of its lime.

Of the other treatments, the sulphuric acid solutions attacked the charlock much more rapidly than the copper sulphate solution (the leaves showed the effect of the 8 per cent. solution in half an hour), and the

4 per cent. acid solution caused about as much destruction of charlock as the copper sulphate solution. The latter was itself more effective when falling on leaves dried by the sun, than it had been in the early morning application on dewy herbage. The 8 per cent. acid solution destroyed the charlock almost completely; it injured the barley rather severely, but this check was outgrown in three weeks' time.

The results of the main series of experiments throw some light on general questions of weed-competition. The serious reduction in yield of barley on the untreated plots through the presence of charlock has already been noted. That the chief element in the competition was the supply of nitrogen rather than that of water, carbon dioxide or sunlight, or the vague factor of 'root room', is clear from the action of the cyanamide. By increasing the final yield of charlock, it intensified the competition for the other factors, yet barley responded to the extra nitrogen and gave a yield much above that in the untreated plot.

In these experiments the final effect of cyanamide on charlock was poorer than that of the other treatments, although in practice many good results have been reported. Korsmo [8] used it successfully but Bolin [9] found that its action as a weed-exterminator was less reliable, because more subject to external conditions, than that of a spray. Long [10] has described some striking examples of its use on various weeds.

Summary

1. Field experiments on the effect of time and method of application of calcium cyanamide to seed-beds showed that there was no interference with germination by dressings up to 3 cwt. per acre, given one week or more before sowing. The interval between sowing the fertilizer and the seed might safely be reduced to a few days, or even in favourable conditions to a few hours, for moderate applications, provided that the fertilizer was cultivated into the soil before the seed was sown. A moderate application two days after sowing the seed was found to be safe if the fertilizer was left undisturbed on the surface of the soil.

2. In a replicated field trial on charlock-destruction in barley, with comparisons under different weather conditions, calcium cyanamide proved much less efficient in destroying the charlock than kainit or a solution of copper sulphate. Both the barley and the weeds that survived the cyanamide-treatment responded to the added nitrogen.

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THE RESPONSE OF GRASSES AND CLOVER TO TREATMENT ON ACIDIC UPLAND SOILS, AND THE EFFECT OF HERBAGE PLANTS ON THE REACTION OF ACIDIC SOILS

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PART II. The effect of herbage plants on *Molinia* soil

With Plate 7

IN addition to the field experiment described in a previous issue of this *Journal* [1] a series of pot experiments was carried out with the same soil. Whilst the main object of the field experiment was to determine

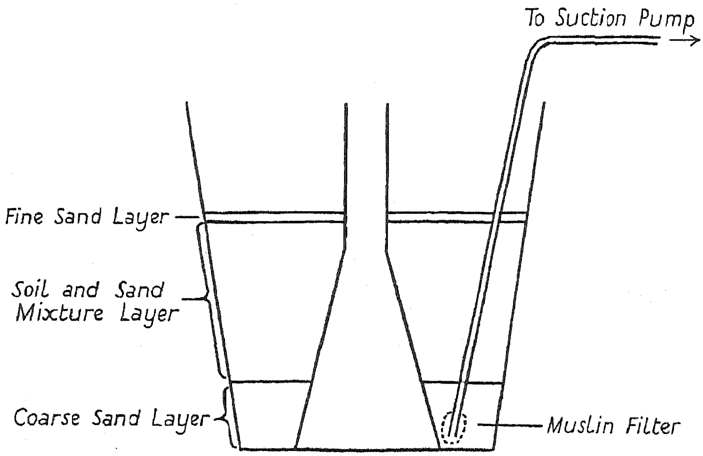

FIG. 1. Sketch of Vessel used in Pot Experiments.

the effect of combined treatments on the herbage produced on the *Molinia* area, the pot experiments were mainly concerned with the influence of the cultivated grasses and wild white clover on the soil. It was thought that pot experiments, in conjunction with the field work, would throw light not only on the effect of the herbage plants on soil acidity, but also on soil nitrogen. Thus one of the objects of the experiment under consideration was to obtain a comparison of the nitrogen metabolism of wild white clover with that of grasses grown under similar conditions but supplied with soluble nitrogen.

With these aims in view, an examination of the drainage-water from the soil on which the plants were grown was necessary, and for this reason a type of pot was adopted similar in several respects to that used by Hoagland [2] and McCall [3]. The essential features of the pot are shown in the accompanying sketch (Fig. 1). The pot was earthenware,

glazed inside and coated on the outer surface by immersion in melted paraffin wax. The pot had a diameter of $6\frac{1}{2}$ in., and a capacity for holding over 1 kg. of soil-sand mixture. Each pot was fitted with an inverted funnel to facilitate drainage and aeration, and a layer of coarse sand was placed at the bottom. A bent glass tube also led to the bottom of the pot, the end immersed in the pot being covered with muslin. The other end could be connected with a receiving vessel and the drainage-water removed into this by means of a suction pump. The *Molinia* soil, after being air-dried so that it could be passed through a 3 mm. sieve, was thoroughly mixed with an equal weight of fine sand, and 1·1 kg. of this mixture, with or without manurial ingredients, was superimposed on the coarse sand layer. On the surface of this soil-sand mixture, 100 seeds of either perennial rye-grass, red fescue, or wild white clover were sown in each pot. These were then covered with a layer of fine moist sand and allowed to germinate. For control purposes, pots were also treated in a similar way without seed. The seeds were sown on March 30, 1931. On June 18 the grass-seedlings were reduced to 50 per pot, and the clover-seedlings to 25 per pot. The pots were kept in an unheated greenhouse, but were removed outside during warm dry weather. They were maintained at a constant weight by the frequent addition of distilled water. The manurial treatments given were as follows:

Pots containing grasses. (Treatment per pot.)

1st Series: No treatment.

2nd Series: 2·3 gm. basic slag+0·4 gm. potassium sulphate.

3rd Series: 2·3 gm. basic slag+0·4 gm. potassium sulphate+5 gm. calcium carbonate+0·2 gm. nitro-chalk. A further quantity of nitro-chalk, amounting to a total of 0·8 gm., was applied during the experiment in periodic doses of 0·2 gm.

4th Series: 2·3 gm. basic slag+0·4 gm. potassium sulphate+5 gm. calcium carbonate+0·4 gm. nitro-chalk. A further quantity of nitro-chalk, amounting to a total of 1·6 gm., was applied during the experiment in periodic doses of 0·4 gm.

Pots containing wild white clover. (Treatment per pot.)

1st Series: No treatment.

2nd Series: 2·3 gm. basic slag+0·4 gm. potassium sulphate.

3rd Series: 2·3 gm. basic slag+0·4 gm. potassium sulphate+5 gm. calcium carbonate.

4th Series: 2·3 gm. basic slag+0·4 gm. potassium sulphate+5 gm. calcium carbonate+0·2 gm. nitro-chalk.

The above treatments were designed to encourage the development of grass in the one case and that of clover in the other. Hence in the third and fourth series the treatment given to the grasses differed from that given to the clover in that a heavy increment of nitrogen was applied to the former. Three cuts of the herbage were taken in 1931, five in 1932, and the final cut was taken in the spring of 1933. The growth obtained prior to the first cut as a result of these treatments is shown in the annexed photographs (Plate 7). It is seen that whereas perennial rye-grass responded very little to slag and potash, its productivity increased

strikingly when calcium carbonate and nitro-chalk were added (Fig. 2). The results with red fescue were similar (Fig. 3). Wild white clover, however, behaved quite differently, no growth occurring in the untreated pots. A marked response, however, followed the application of slag and potash, and calcium carbonate and nitro-chalk produced no further striking effect (Fig. 4).

The herbage cuts taken from the pots were dried and analysed. Samples of drainage-water were also withdrawn for determining pH by the quinhydrone-electrode method and nitrate by the phenol-disulphonic-acid method.

Effect of Herbage Plants on the Hydrogen-ion Concentration of Soil and of Soil Drainage

The hydrogen-ion concentration of the soil-sand mixture could, of course, only be determined when the pot experiments were ended. These determinations were, however, supplemented by determinations on soil samples taken at intervals from the plots in the field experiment on the same soil [1]. As the findings obtained in the one case have an important bearing on those obtained in the other, the results from both sources will be considered at this stage. The results from the field plots are shown in Table 1; they were obtained from samples taken on seven different dates spread over the period.

TABLE 1. *pH of Soil Samples from Field Plots subjected to Different Treatments*

Treatment	*pH* Max.	*pH* Min.	*pH* Mean of 18 determinations
Nil	4·26	3·59	3·89
Cultivation and seeding	4·21	3·73	3·93
Cultivation, seeding + 12 cwt. basic slag	4·69	4·16	4·41
Cultivation, seeding + 8 cwt. nitro-chalk	4·54	4·04	4·20
No cultivation + 12 cwt. basic slag; 8 cwt. nitro-chalk	4·83	4·52	4·59
Cultivation, no seeding + 12 cwt. basic slag; 8 cwt. nitro-chalk	4·80	4·50	4·63
Cultivation, seeding + 12 cwt. basic slag; 8 cwt. nitro-chalk	5·05	4·28	4·56
Cultivation, seeding + 12 cwt. basic slag; 5 cwt. limestone	4·78	4·20	4·48
Cultivation, seeding + 12 cwt. basic slag; 20 cwt. limestone	4·94	4·55	4·81
Cultivation, seeding + 12 cwt. basic slag; 20 cwt. limestone; $1\frac{1}{2}$ cwt. K_2SO_4	5·00	4·53	4·73
Cultivation, seeding + 12 cwt. basic slag; 20 cwt. limestone; $1\frac{1}{2}$ cwt. K_2SO_4; $\frac{3}{4}$ cwt. nitro-chalk	5·04	4·44	4·69
No cultivation + 12 cwt. basic slag; 20 cwt. limestone; $1\frac{1}{2}$ cwt. K_2SO_4; $\frac{3}{4}$ cwt. nitro-chalk	5·12	4·49	4·87

The difference between the maximum and minimum values obtained from the same plots, shown in Table 1, affords an indication of the seasonal fluctuation in the soil pH. Similar fluctuations that are probably

related to the variations in the concentration of soil electrolytes [4, 5] have been observed in other soils [6]. The above table shows that cultivation and seeding without manuring have had no significant effect on the pH. In those soils to which basic slag was applied, a marked increase in pH occurred. Where nitro-chalk was applied a smaller change resulted, but slag and nitro-chalk applied together produced a greater effect than when they were applied separately. The greatest effect on the pH was obtained in those plots where 1 ton of limestone was included in the manurial dressing.

The difference in pH value between the unmanured and manured plots was so great that it was considered likely that the greater growth of herbage in the manured plots, as compared with the unmanured, played a part in bringing about this lowering of soil acidity. Smith and Robertson [7] have previously shown the importance of the growing potato in diminishing the seasonal increase of soil acidity occurring in unplanted soil. In order to determine the significance of herbage plants in their effect on the pH of the acidic upland soil dealt with in this experiment, samples of the soil were incorporated with slag, with and without limestone. These were kept in the dark at room temperature, washed with water, the water removed by filtration, and the soil afterwards dried to simulate field conditions. The pH value was determined at intervals, and a comparison of the results with those obtained with the field soils in which herbage plants had grown is given in the next table.

TABLE 2. *pH Values of Soils from Seeded Field Plots compared with those of Unplanted Soil in the Laboratory*

	Seeded field plots				*Laboratory soil*			
	Total CaO in manure (tons per acre)	*pH*			*Total CaO in manure (tons per acre)*	*pH*		
Manurial treatment		*Max.*	*Min.*	*Mean*		*Max.*	*Min.*	*Mean*
Nil	..	4·21	3·73	3·93	..	4·28	3·78	4·05
Basic slag	0·24	4·69	4·16	4·41	0·40	4·45	3·87	4·18
Basic slag + limestone	0·38	4·78	4·20	4·48	0·66	4·50	3·86	4·19

Table 2 shows that although more basic slag and limestone were applied to the laboratory soil than to the field soil, the change in pH of the field soil was much greater than that in the unplanted laboratory soil. This suggests that the increased herbage following the manurial treatment in the field soil was an important factor in modifying the soil acidity; and it is clear from Table 1 that the native *Molinia* pasture and the sown species are equally effective in this respect. The lowering of soil acidity by the action of the fibrous roots of other plants such as alfalfa, rye, vetch, and maize, has been shown to take place by Thom and Humfeld [8]. Thus with corn, a fallow soil outside the root-zone gave a pH of 4·5, the soil adjacent to the roots showed a pH of 4·8; and another soil of pH 6·1 gave a pH of 6·9 adjacent to the roots of rye. Thom and

Humfeld further show that the significance of this change produced by the plant lies in the fact that the roots create a narrow zone favourable to the activity of bacteria and moulds.

Further information regarding the effect of the herbage plants on the pH of both drainage-water and soil is derived from a consideration of the data obtained in the pot experiments. The pH values of the drainage-water and of the soil in those pots where the seed was sown, and also in unseeded pots, are given in Table 3. In order to obtain a strict comparison between the grasses and clover, those pots to which basic slag and potassium sulphate only were applied have been chosen, this being the series in which grasses and clover received identical manurial treatment.

TABLE 3. *The Effect of Grasses and Wild White Clover on the pH Value of Drainage-water and of Sand-soil Mixture*

	pH of drainage water					*pH of soil-sand mixture*
Date	*22/9/31*	*2/6/32*	*20/9/32*	*20/1/33*	*Mean*	*(4/5/33)*
Unseeded soil	6·07	5·20	4·68	4·79	5·19	5·01
Perennial rye-grass	5·99	5·78	6·01	5·14	5·73	5·39
Red fescue	6·03	5·61	6·13	5·51	5·82	5·42
Wild white clover	5·29	4·90	5·66	5·65	5·38	5·25

Table 3 shows that a marked increase in the acidity of the drainage-water occurred in the unseeded soil from September 1931 to September 1932. Where the herbage plants were growing, this accumulation of acidity did not occur, with the result that the mean pH value of the drainage-water was higher where the herbage plants were grown than in the unseeded soil. A higher acidity in the drainage was obtained from clover than from the grasses up to and including September 1932. In January 1933, however, when no active growth occurred the position was reversed, a higher acidity being obtained from drainage under the grasses, more particularly the perennial rye-grass. Taking all the determinations into consideration, it will be seen that the drainage from the clover pots showed a higher acidity than that from the grass pots. In the latter there was no significant difference between the effect of the rye-grass and that of red fescue.

The pH value of the soil-sand mixture taken at the end of the experiment also shows a definite lowering of acidity in the pots containing the herbage plants. This effect was somewhat greater with the grasses than with the wild white clover.

The Effect of Various Factors on the Nitrate-nitrogen Concentration in the Drainage-water

The pots in which no seed was sown afforded a means of ascertaining the effect of different manurial treatments on the drainage-water from uncropped soil. The two principal manurial treatments consisted of (*a*) basic slag+sulphate of potash, and (*b*) these manures with the addition of

limestone and nitro-chalk, the nitro-chalk being applied in increments during the experimental period. Table 4 shows the effect of these two treatments on the nitrate-nitrogen concentration in the drainage-water.

TABLE 4. *Effect of Manurial Treatment on Nitrate-nitrogen Concentration of Drainage from Uncropped Soil. (Concentration expressed in p.p.m. nitrate nitrogen.)*

Manurial treatment	22/5/31	16/7/31	22/9/31	21/6/32	20/9/32	20/1/33
A. Nil	1·64	0·212	0·826	11·29	11·94	10·42
B. Basic slag + K_2SO_4 .	negligible	4·28	19·21	35·27	99·99	70·80
C. As B + limestone + nitro-chalk . .	12·15	174·40	164·80	103·30	190·00	180·00

The manures, including the first increment of nitro-chalk, were incorporated with the soil on March 28, 1931. About two months after this application, the nitrate-concentration was negligible where basic slag and sulphate of potash had been applied. At the same time a low, but appreciable, concentration was found in the drainage from the untreated soil. This phenomenon is probably due to the rise in bacterial numbers that follows the application of phosphatic manures [9]. This rise would make increased demands on the soluble nitrogen and account for a temporary depletion in the drainage. It is evident from Table 4 that the subsequent mineralization of these increased bacterial numbers has ultimately resulted in a much higher nitric-nitrogen concentration than in the untreated soil.

The total quantity of soluble nitrogen as ammonium nitrate applied during 1931 was equivalent to a concentration of 152 p.p.m. The results from the drainage for this year therefore indicate not only that all the nitrogen of the ammonium nitrate was converted during the same season to the nitrate form, but also that soil nitrogen was nitrified in addition.

Table 5 compares the nitric nitrogen in the drainage from the uncropped soil with that in the drainage-water from those pots where grasses and wild white clover were grown.

TABLE 5. *The Effect of Grasses and Clover on the Nitrate-nitrogen Concentration (p.p.m.) of Soil Drainage-water*

	22/5/31	16/7/31	22/9/31	21/6/32	20/9/32	20/1/33
Series 1. Unseeded soil .	12·15	174·4	164·8	103·3	190·0	180·0
Series 2. Perennial rye-grass . . .	1·29	0·21	0·17	0·28	0·64	1·12
Series 3. Red fescue .	2·71	0·26	1·33	negligible	0·42	0·91
Series 4. Wild white clover . . .	1·09	0·40	0·14	5·07	negligible	5·48

The manurial treatment was identical for the first three series in the table, and included basic slag, sulphate of potash, limestone, and increments of nitro-chalk. In series 4—wild white clover—no nitro-chalk was applied, the manurial treatment being otherwise the same. The table shows that both perennial rye-grass and red fescue remove the nitrate

from the drainage-water with remarkable efficiency, even when present in high concentrations. The maximum concentration in those pots where these grasses were grown at no time reached the low level attained in the drainage from unmanured soil on which no crop was grown (Table 4, manurial treatment A). These figures emphasize the important part played by a vigorously growing grass in conserving the soluble nitrogen, and minimizing the loss through drainage.

In the pots of wild white clover the concentration of nitrate has been low throughout, as compared with that obtained by the application of nitro-chalk to unseeded soil. It is, however, significant to find that, although no nitro-chalk was applied to the wild white clover, a maximum concentration of 5·48 p.p.m. nitrate-nitrogen was attained in the course of the experimental period, whilst with the grasses the maximum concentration reached was 2·71 p.p.m., in spite of the heavy application of soluble nitrogen. It should be pointed out that the concentrations of nitrate-nitrogen found in the drainage where wild white clover was grown give no indication of the rate at which the clover can supply grasses with soluble nitrogen. The rate at which atmospheric nitrogen is converted into the soluble form may depend largely on the rapidity with which this soluble nitrogen is removed from the drainage water, a rapid removal leading to a high efficiency of fixation [10].

Nitrogen removal from soil by perennial rye-grass and red fescue.—In Table 6 the nitrogen removed from the soil by the grasses as a result of various treatments is shown and compared with the amount of nitrogen applied as manure.

TABLE 6. *Comparison of Nitrogen removed from Soil by Grasses with the quantity supplied in Manure. Nitrogen expressed in mg. per pot; A = applied in manure, R = removed in grass.*

		1931		*1932*		*1933*	
Series	*Manurial treatment*	*A*	*R*	*A*	*R*	*A*	*R*
	Perennial rye-grass						
1	Nil	Nil	23·6	Nil	54·1	Nil	23·9
2	Basic slag and K_2SO_4	Nil	40·7	Nil	82·5	Nil	29·3
3	As 2+limestone+nitro-chalk	62·0	190·4	93·0	111·2	31·0	29·5
4	As 3 but double nitro-chalk supply	124·0	248·8	186·0	131·0	62·0	35·4
	Red fescue						
1	Nil	Nil	19·7	Nil	67·8	Nil	28·8
2	Basic slag and K_2SO_4	Nil	28·9	Nil	98·7	Nil	21·8
3	As 2+limestone+nitro-chalk	62·0	219·8	93·0	125·8	31·0	27·0
4	As 3 but double nitro-chalk supply	124·0	262·7	186·0	199·2	62·0	43·3

From the point of view of the capacity of the plant to recover nitrogen applied in the soluble form, the results for the first season, before root-congestion had become serious, are of greater significance than those obtained for later years. When the results for this season are considered

it is evident that in Series 3 and 4 much more nitrogen was removed in the plant than was supplied in the manure.

In Series 3 it is seen that during the first season the perennial rye-grass not only recovered all the nitrogen supplied as manure, but derived 88 mg. more nitrogen from the soil than it obtained when no nitrogenous manure was applied (Series 2). Again, in Series 4, not only was the nitrogen recovered completely from the manure, but in addition 84 mg. more nitrogen were derived from the soil than in Series 2. It will be noted that under the pot-culture conditions, and with the soil employed in this experiment, a greater response to limestone and nitro-chalk was obtained from red fescue than from perennial rye-grass. Thus for red fescue 129 mg. more nitrogen were obtained from the soil in Series 3 than in Series 2, and 110 mg. more nitrogen in Series 4 than in Series 2.

These results are in agreement with data previously obtained in the field, where the large recovery of nitrogen from nitro-chalk could only be explained on the assumption that increased quantities of soil nitrogen became available to the plant as a result of applying the manure [11].

Protein-synthesis by grasses and wild white clover.—In Table 7 the amount of plant-protein synthesized by the grasses is compared with that synthesized by wild white clover.

TABLE 7. *Comparison of Protein-Synthesis by means of Grasses and Wild White Clover under Pot-culture Conditions. Experimental Period 30/3/31 to 4/5/33. Nitrogen yields expressed in mg. per pot.*

	Nitrogen yielded by perennial rye-grass (Lolium perenne)			*Nitrogen yielded by red fescue* (Festuca rubra)			*Nitrogen yielded by wild white clover* (Trifolium repens)		
Manurial treatment	*From manure*	*From soil*	*Total*	*From manure*	*From soil*	*Total*	*From manure*	*From air*	*Total*
A. Nil	Nil	102	102	Nil	116	116	Nil	Nil	Nil
B. Basic slag + sulphate of potash	Nil	153	153	Nil	149	149	Nil	928	928
C. Basic slag + sulphate of potash + limestone + nitro-chalk for grasses; none for clover	186	145	331	186	187	373	Nil	1,007	1,007
D. Basic slag + sulphate of potash + limestone + much nitro-chalk for grasses and little for clover	372	43	415	372	133	505	31	989	1,020

Table 7 shows that under the pot-culture conditions adopted in this experiment the synthesis of protein took place at a much higher rate in wild white clover than in perennial rye-grass and red fescue. Where no nitrogenous manures were applied (Series B), protein-synthesis occurred only at one-sixth the rate of that taking place in wild white clover. Where the grasses were intensively treated with limestone and nitrogen (Series C and D), a phenomenal increase in the rate of protein-synthesis occurred, but even this accelerated process showed at its maximum only half the rate of synthesis attained by the clover.

In spite of this much greater protein-synthesis by means of clover, the soil in which it was grown was found to be definitely richer in nitrogen

at the end of the experiment than the soil in which the grasses were grown. This is made clear in Table 8.

TABLE 8. *The Effect of Grasses and Wild White Clover on the Percentage Total Nitrogen of Soil-sand Mixture*

Crop	*Nitrogen in manure*	*Percentage total nitrogen in soil-sand mixture at end of experiment*		
		Maximum	*Minimum*	*Mean*
	Series 1. Manurial treatment—basic slag + K_2SO_4			
Nil	Nil	0·216	0·198	0·203
Perennial rye-grass	Nil	0·203	0·193	0·197
Red fescue	Nil	0·209	0·197	0·201
Wild white clover	Nil	0·227	0·203	0·209
	Series 2. Manurial treatment—basic slag + K_2SO_4 *limestone and nitro-chalk*			
Nil	0·034	0·225	0·219	0·222
Perennial rye-grass	0·034	0·210	0·208	0·209
Red fescue	0·034	0·203	0·203	0·203
Wild white clover	0·003	0·226	0·212	0·220

In Series 1, the growth and removal of young grass have slightly diminished the nitrogen-content of the soil, but the nitrogen concentration has been increased as a result of the growing and frequent removal of wild white clover. In Series 2, although the nitrogen-content of the clover soil is slightly lower than that of the control, a definite gain of soil nitrogen has been accomplished by the clover over the control, seeing that much more nitrogen was applied as manure to the control soil. It is evident that in spite of the fact that the grasses received more nitrogen as manure and supplied less plant-protein than the clover, the reserves of nitrogen are higher in the clover soil than in the soil on which the grasses were grown.

Summary and Conclusions

The field experiments described in Part I [1] were supplemented by a series of pot experiments with the object of comparing the effect of cultivated grasses with that of wild white clover on the acidity and the nitrogen metabolism of the *Molinia* soil. It was recognized that the effect of these plants on the soil might be quite different when treated as pasture from their effect if allowed to reach the more mature stage of a hay crop. As information was desired regarding their effect when grown as pasture, cuts were taken at frequent intervals from the pots during the experimental period. Both the growing plants and the drainage-water were examined, the nitrogen-content of the soil being also determined. The following conclusions are drawn from the data obtained:

1. Both the grasses and the wild white clover lower the acidity of the soil and drainage water, the effect of the former being somewhat greater than that of the latter. Whilst the direct effect of small dressings of basic slag and limestone on the pH of this acid soil is very small, the indirect

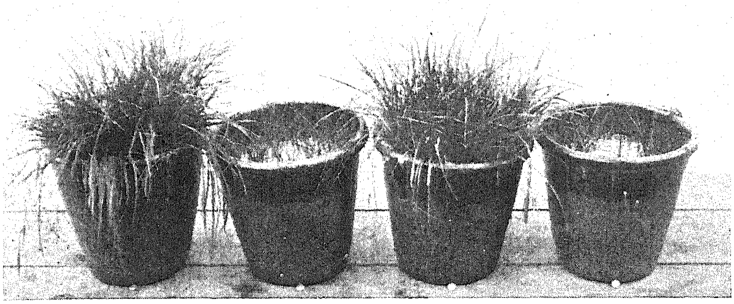

FIG. 2. Response of Perennial Rye-Grass to Manurial Treatment
a. 4th Series. Slag + K_2SO_4 + $CaCO_3$ + Nitro-chalk (·8 gm.)
b. 2nd Series. Slag + K_2SO_4
c. 3rd Series. Slag + K_2SO_4 + $CaCO_3$ + Nitro-chalk (·4 gm.)
d. 1st Series. No manure

FIG. 3. Response of Fescue (*Festuca rubra*) to Manurial Treatment
a. 4th Series. Slag + K_2SO_4 + $CaCO_3$ + Nitro-chalk (·8 gm.)
b. 2nd Series. Slag + K_2SO_4
c. 3rd Series. Slag + K_2SO_4 + $CaCO_3$ + Nitro-chalk (·4 gm.)
d. 1st Series. No manure

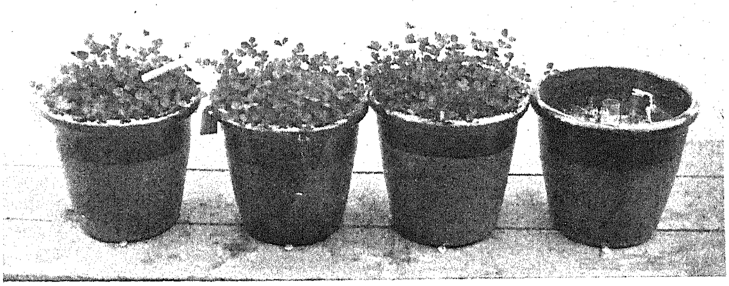

FIG. 4. Response of Wild White Clover to Manurial Treatment
a. 3rd Series. Slag + K_2SO_4 + $CaCO_3$
b. 2nd Series. Slag + K_2SO_4
c. 4th Series. Slag + K_2SO_4 + $CaCO_3$ + Nitro-chalk (·2 gm.)

effect is much greater, in that the increased herbage growth which they encourage has a decided influence on the pH of the soil.

2. Examination of the drainage-water reveals that nitrate-nitrogen, even when present in high concentration, is removed with great rapidity by the grasses. Vigorously growing herbage thus plays an important part in conserving the soluble nitrogen. The rapid rate at which the grass removes soluble nitrogen from the drainage may also be a factor in increasing the rate at which the wild white clover associated with it can fix atmospheric nitrogen.

3. The nitrogen applied as nitro-chalk during 1931 was completely recovered in the grasses during the same season. The results further show that the effect of calcium carbonate and ammonium nitrate during this season was to increase the availability of soil nitrogen.

4. A much more rapid synthesis of plant-protein was obtained in the pots where wild white clover was grown than in those pots where perennial rye-grass and red fescue were treated intensively with soluble nitrogen.

5. In spite of the greater amount of plant-protein removed from the wild white clover grown in pots, and the heavy increments of nitrogenous manure applied to the grasses, more total nitrogen could be accounted for in the soil in which the wild white clover had been grown than in that growing perennial rye-grass and red fescue.

Acknowledgements

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SOIL CONDITIONS IN EAST ANGLIA

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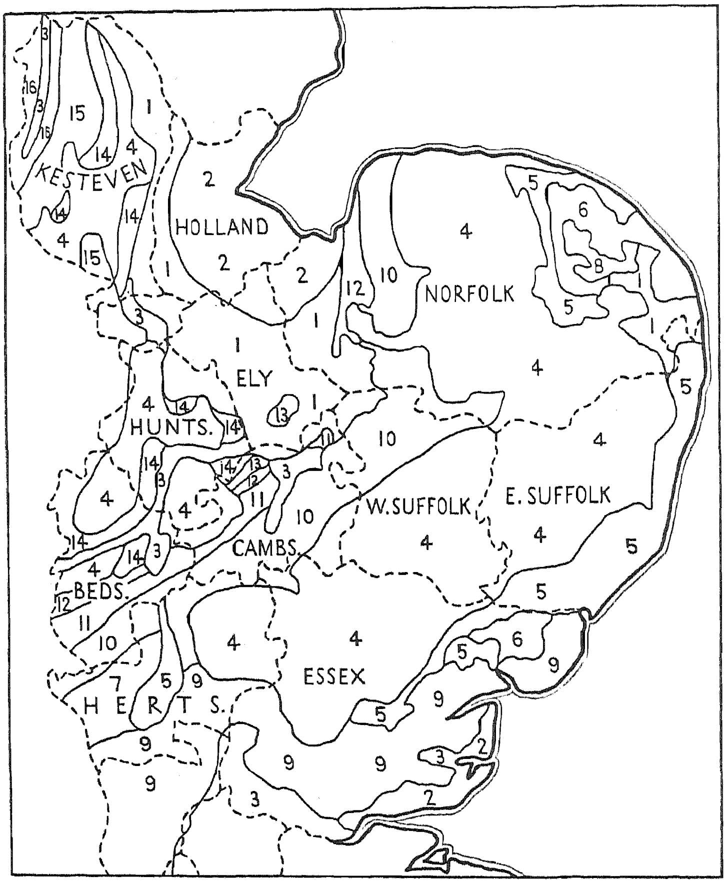
Physiography.—The Drift Map of the Geological Survey is still the best available basis for an account of the soils of East Anglia. The two principal factors involved are parent material and local physiography. The



Diagrammatic Drift Map of the Eastern Counties.

(Approximately 17 miles to 1 inch)

1. Alluvium—Peat.
2. Alluvium—Silt.
3. Valley Gravel.
4. Boulder Clay.
5. Glacial Gravel.
6. Glacial Loam.
7. Clay with Flints.
8. Norwich Crag.
9. London Clay.
10. Chalk.
11. Gault.
12. Lower Greensand.
13. Kimeridge Clay.
14. Oxford Clay.
15. Oolite.
16. Lias.

former, over by far the greater part of this region, is provided by the most recent deposits, particularly drifts of various types. The strike of the solid strata is in a SW. to NE. direction veering through a S. to N. line to a SSE.–NNW. line in the northern half, whilst the dip is towards the

SE. and E. accordingly. The main formations involved are the Norwich and Coralline Crags, the London Clay, the Chalk, the Gault, the Lower Greensand, the Kimeridge Clay, the Oxford Clay, the Oolite, and the Lias. The Chalk and Oolite respectively give rise to two main ridges of high land, starting in the SW. The former gives the high land of Hertfordshire, SE. Cambridgeshire, N. Essex, W. Suffolk, and W. Norfolk, whilst the latter accounts for a broken belt of high land starting in Bedfordshire and running north to Kesteven (Lincolnshire).

Between these two areas of high land lies the lower portion of the catchment area of the rivers draining into the Wash. Between the Chalk ridge and the east coast, the level of the country gradually falls and its surface is intersected by the valleys of the rivers of Essex, Suffolk, and Norfolk. Throughout the whole area the lowlands reflect the outcrops of the clay formations, although to a great extent these are covered by alluvial deposits.

Recent drift-deposits cover by far the major portion of East Anglia. A broad belt of Boulder Clay extends from the north coast of Norfolk, through Suffolk and N. Essex into Hertfordshire and intermittent but extensive areas of this deposit occur in N. Bedfordshire, Huntingdonshire, and Kesteven. Around the coastal fringe of the main expanse, and in all the river valleys which intersect it, there are exposures of Glacial Gravel and Sand, notably in NE. Norfolk, E. Suffolk, NE. Essex, and mid-Hertfordshire. The area of Glacial Loams is smaller still, but is prominent in NE. Norfolk and NE. Essex. The Fen country occupies a considerable portion of the whole area, almost surrounding the Wash, and is covered by various alluvial deposits of silt, peat, and valley gravels. Between the main eastern expanse of Boulder Clay and the Fen deposits, runs a belt of exposures, mostly of the Chalk, but also of the Gault, the Lower Greensand, and Kimeridge Clay. These continue intermittently through Cambridgeshire into Bedfordshire. On the flanks of the main area are found considerable areas of clay, the London Clay in S. Essex and Hertfordshire, the Oxford Clay in Bedfordshire and Huntingdonshire, and the Lias in Kesteven.

Parent Material.—Three main types of parent material are found in East Anglia:

Clay	*Sand and Gravel*	*Limestone*
Alluvium	Alluvium	Chalk
Boulder Clay	Valley Gravel	Lincoln Limestone
Clay with Flints	Glacial Sand and Gravel	Cornbrash
London Clay	Norwich and Coralline Crag	
Gault	Bagshot Beds	
Kimeridge Clay	Lower Greensand	
Oxford Clay	Northampton Sands	
Lias Clay		

Drainage Conditions.—The widespread occurrence of drift-formations and the great variation in the parent materials within a single formation, such as the Boulder Clay, coupled with the diverse topography with

which they are associated, inevitably produce a wide range of drainage-conditions. Thus, in the case of the Boulder Clay, permeability varies from very low to very high values. Fortunately, however, the formation is associated mainly with high land or definite slopes. The Gault, on the other hand, is chiefly associated with low land, and flat or depressed areas. The Glacial and older River Gravels, again, are mostly so located as to be free draining, but many areas of Valley Gravels are on low ground with a naturally high water-table. The Fen basin with its large range of parent materials is wholly depressed, much of it very near sea-level and dependent on extensive schemes of artificial drainage to keep it above water. With such a cross variation of two of the main factors, parent material and drainage, the determination of soil series is a task of some magnitude. Furthermore, East Anglia, constituting as it does the predominantly arable part of this country, has been subjected to human influence to a marked degree. The practices of draining, claying, chalking, tillages, and manuring have been extensively applied, some of them over considerable periods, and have inevitably rendered the study and classification of the soils more difficult.

Soils of the Boulder Clay.—The enormous area of Boulder Clay in the eastern counties has been indicated. It is by no means uniform throughout its extent in respect either of thickness or constitution. Thus in Hertfordshire, Huntingdonshire, Cambridgeshire, Essex, and mid-Suffolk it is a heavy blue clay, in E. Suffolk it is a sandy clay, in W. Suffolk and NW. Norfolk it is often described as disturbed chalk. On the flanks of all areas it thins out considerably and in a general way also it gets thinner and less clayey from west to east and from Essex to Norfolk. Bands of sand and gravel are common, especially in marginal areas. Typical exposures show a moderately warm, brown, heavy soil lying on a lighter yellow-brown, clay subsoil which, at a depth of several feet, merges into a dark grey or blue clay. The whole is charged to a greater or less extent with fragments of chalk, flints, and stones of all descriptions. In contrast with this heavy material, one finds in NW. Suffolk a sandy surface layer, more chalky, lying on a brown sandy clay subsoil. Farther north the material appears to be chiefly chalk debris or yellowish-white loamy marl.

The variations in the parent material are closely reflected in the nature of the soils. Heavy clay soils predominate in Huntingdonshire, N. Bedfordshire, W. Cambridgeshire, N. Hertfordshire, and NW. Essex, but, proceeding from Essex to Norfolk, the soils as a whole get steadily lighter, with all gradations of texture to the extreme of very coarse sands. Typical mechanical analyses are given in Table 1 (these analyses were originally performed by the 1906 A.E.A. method, and the results have been approximately converted to the present scale by plotting summation curves and deriving the new figures by interpolation).

The distribution of soil types on a broad texture basis within the Boulder Clay area is illustrated in Table 2 which gives the results of a general soil survey of the area, carried out by the School of Agriculture, Cambridge, some years ago.

In the main the Boulder Clay is distinctly calcareous, much of the chalk

TABLE 1. *Analyses of Boulder Clay Soils (per cent.)*

County:	Kesteven	Hunts.	Herts.	Essex	Essex	W. Suffolk	E. Suffolk	Norfolk	Norfolk
Locality:	Gt. Ponton	Abbotsley	Ardeley	Stapleford Abbots	Halstead	Walsham-le-Willows	Yaxley	Pulham Market	Stanhoe
Soil									
Coarse sand	11·2	11·6	10·9	19·1	23·4	36·7	37·0	45·4	56·8
Fine sand	20·8	16·3	19·7	31·6	35·3	28·6	25·1	32·0	28·7
Silt	20·4	15·8	19·3	18·3	19·5	8·7	7·8	8·9	5·6
Clay	29·6	35·8	31·6	19·4	14·2	17·0	15·8	12·3	3·6
$CaCO_3$	0·45	0·7	2·0	..	0·52	1·5	5·0	0·32	0·55
Subsoil									
Coarse sand	12·0	10·6	10·8	14·2	18·3	30·1	32·9	50·6	54·5
Fine sand	20·5	16·8	18·1	29·3	34·3	23·5	25·4	22·6	26·3
Silt	18·0	18·7	17·6	16·2	16·6	8·3	8·9	6·8	4·9
Clay	35·5	36·3	33·7	29·4	21·2	27·5	19·5	12·1	4·2
$CaCO_3$	1·6	1·7	5·7	..	0·17	0·99	5·9	0·76	1·31

TABLE 2. *Texture of Boulder Clay Soils*

Area	*No. of samples examined*	*Per cent. distribution of samples on texture basis*				
		Clays	*Heavy loams*	*Medium loams*	*Light loams*	*Sandy soils*
Kesteven	16	13	31	38	18	0
Huntingdonshire	24	38	38	20	4	0
Bedfordshire	23	48	26	4	22	0
W. Cambridgeshire	11	45	55	0	0	0
Hertfordshire	30	13	50	20	14	3
Essex	60	7	39	22	30	2
E. Cambridgeshire	8	0	75	25	0	0
W. Suffolk	41	0	32	22	32	14
E. Suffolk	52	2	8	15	58	17
Norfolk	68	2	9	19	38	32
Total all areas	333	11	28	19	30	12

existing in rounded pebbles and granules in the clay matrix. In general the amount is much greater in the subsoil than in the topsoil. The most chalky areas coincide with the heaviest soils; thus chalk contents of 5 to 20 per cent. are the rule in Bedfordshire, Huntingdonshire, W. Suffolk, and Essex, while the lowest figures are met with in the more open soils of the eastern fringes of the formation, and in E. Suffolk and Norfolk, where the figures as a rule lie between 0·1 and 5 per cent.

Agriculturally, the Boulder Clay soils comprise a wide range of textures from the easily worked light loam soils in the north of the province to the heavy clay of NW. Essex in the south and Bedfordshire and Huntingdonshire in the west. These soils cover a large part of the area from which the Eastern Counties have derived their reputation for arable farming. Some 70 per cent. of the Boulder Clay area is arable, the system of cropping for the most part being a four-course rotation modified in some cases to meet individual requirements or market conditions. In this way approximately half the arable land carries cereal crops, one-quarter roots or fallow, and one-quarter leguminous crops.

Where the soils are lighter in texture, barley is the chief cereal crop, conditions being favourable for the production of a good malting sample. There is also a fair acreage of wheat, whilst of the root-crops, sugar-beet has assumed a position of considerable importance during recent years. On the heavier soils wheat is the most important cereal crop, and, though sugar-beet is still grown to some extent, it is of much less importance here than on the lighter soils. These heavy soils are also noted for seed-production, especially the seed of clovers and root-crops.

The live-stock industry also changes in passing from north to south in the Boulder Clay area. In central Norfolk, dairying is now an important industry, whilst on the lighter soils of NW. Norfolk sheep are still a feature of the district. Passing south, live stock gradually become a less conspicuous feature, until in NW. Essex they are, on many farms, of relatively little importance. Concurrently there is also a change in the type of live stock for, travelling from north to south, both fattening and

dairy cattle become gradually less prominent, whilst the pig industry becomes progressively more important, rising to a maximum in central Suffolk and thence, in common with other types of live stock, steadily decreasing in importance.

It is perhaps worthy of note that in recent years an appreciable acreage of market-garden crops, such as Brussels sprouts, cabbage, broccoli, and carrots, have been grown on many farms in this Boulder Clay area, especially on the light and medium loams.

Soils of the Glacial Gravel.—Glacial Gravel assumes prominence round the eastern flanks of the Boulder Clay area. The formation is composed variously of layers of coarse gravel, coarse or fine sand, and occasionally loam or clay. The pebbles in it are mostly of flint, quartz, or hard chalk. There is evidence of calcareous cementation in the horizons immediately below the Boulder Clay. In the main the larger areas of this formation produce very sandy soils, but in the valleys, by the action of the rivers, where it has been exposed in long narrow strips, the higher lying Boulder Clay has contributed a proportion of fine particles and the soils are loamy sands and gravelly loams. The clay fraction in these soils varies from 1·5 up to 12 per cent., the coarse sand from 70 to 25 per cent., and the fine sand from 13 to 40 per cent. The amount of the clay fraction determines the use to which these soils are put. Considerable areas are almost devoid of this constituent and as a result are heaths. Some of the soils of the Suffolk coastal belt have enough to make them useful agriculturally, whilst in Essex and Hertfordshire the clay fraction is sufficiently high to give easy working and fertile soils. The lightest soils carry the lowest calcium-carbonate content, and although many individual samples show 1 per cent. or more, many contain less than 0·1 per cent., and quite a number are acid in reaction.

The Glacial Gravel soil types are illustrated in Table 3.

TABLE 3. *Analyses of Glacial Gravel Soils (per cent.)*

County:	Kesteven	Suffolk	Essex	Essex
Locality:	Collingham	Thorington	Paglesham	Tolleshunt
Soil				
Coarse sand	70·2	57·1	34·2	37·5
Fine sand	13·5	23·4	34·4	30·0
Silt	6·1	7·7	14·5	15·7
Clay	2·7	5·9	9·8	12·3
$CaCO_3$	0·22	0·06	0·12	0·42
Subsoil				
Coarse sand	79·3	58·4	34·0	21·9
Fine sand	8·3	24·3	34·3	30·2
Silt	6·3	6·7	14·8	17·9
Clay	2·5	7·1	10·2	17·1
$CaCO_3$	0·15	0·03	0·02	0·05

The Glacial Gravels give rise to very diverse types of farming, depending not only on soil variation but also on local market conditions. The

main area, forming the coastal belt in Suffolk, provides examples of the wide differences existing within the group. The northern portion of this belt is, as in the case of the Boulder Clay area, generally lighter in texture than the southern portion. In addition, the southern parts of the area have the advantage of proximity to two large consuming centres, Ipswich and Colchester. In general, where these soils are near to a local market, they are devoted to a relatively intensive type of farming. From half to two-thirds of the land is arable, and of this about half is devoted to cereal crops. Potatoes and market-garden crops form an important part of the remaining arable acreage, though sugar-beet is extensively grown where a factory is within easy reach of the farm. Live stock are an important feature of the farming, especially dairy cattle and poultry.

Where no local consuming centre is available the type of farming is much less intensive. There is little market-gardening, and sugar-beet has generally come to assume the position of the most important root or fallow crop. Sheep play a greater part in the agriculture of these districts but dairying is still important. Considerable areas of the lightest of these soils are at present uncultivated, the high proportion of coarse sand rendering them both infertile and subject to drought. Such areas constitute the typical 'heaths' of this coastal belt. Several large tracts have in recent years been taken over for afforestation.

Soils of the Alluvial Deposits.—Next in importance after the glacial deposits come those of an alluvial nature, accounting as they do for the Fen area, the Thames estuarine and Essex coastal flats, the valleys of the Fen rivers, and the Norfolk Broads district. Round the mouths of the rivers, especially along the Essex coast and that of the Wash, the alluvium consists in part of heavy silts or clays, but mainly, especially in the latter area, of fine sands. The inland parts of the Fen basin are covered with soils derived from Fen peat, whilst round the inland borders of this flat country and along the banks of the existing rivers in their upper parts, considerable areas of Valley Gravel are to be found. Most of these areas have a naturally high water-table, and although the soils are free-draining, they are for the most part dependent on arterial-drainage schemes combined with pumping on an extensive scale.

The Alluvium is characterized by rapid lithological variations both vertically and horizontally, but the prominence of fine sand and silt amongst the mineral particles is noteworthy. The deposits often contain marked amounts of soluble salts, attributable to their marine origin, and locally, saline waters are a well-known cause of spraying difficulties. The precise incidence of this aspect of the soil morphology has not been worked out.

The Fen peat consists of an accumulation of organic matter singularly free from mineral particles, and several feet thick, lying on clays of Lower Cretaceous and Jurassic origin. It has accumulated under swamp conditions in the presence of calcareous water. The whole area is very little above sea-level and much of it is below the level of the rivers running through it. In Wicken Fen, the chief undrained and uncultivated area, the peat, and the water in it, are alkaline. Layers of freshwater shell marl are common in exposures, and calcite is found on the sub-aqueous

vegetation in the ditches. The cultivated black fenland has been considerably modified by artificial drainage and the practice of claying, even in those areas where intrusive mineral matter (sand, clay, or silt) is not an initial cause of variation.

The Valley Gravels consist of deposits of flints, pebbles, chalky gravel, and sand, most widespread at the foot of the high lands surrounding the Fens and along the Thames estuary. The chalky gravel is more characteristic of the older deposits, whilst the sand seems to be a feature of those of more recent origin. The wide range of alluvial soil types is illustrated in Table 4.

The following is a description of a soil profile on Old River Gravel at Cambridge in a slightly elevated position, with free drainage:

0 to 8 in.	Dark grey-brown, gravelly, coarse sandy soil.
8 to 14 in.	Similar, but lighter and richer brown colour.
14 to 20 in.	Light-brown, coarse gravelly sand.
20 to 38 in.	Compact, orange-brown, clay-sand with rusty iron pan at base.
38 in. +	Very flinty sand with fragments of chalk.

Analysis (per cent.)

	0–8 in.	*8–20 in.*	*20–38 in.*
A.E.A. 1927 Method			
Coarse sand	53·97	55·50	54·40
Fine sand	19·01	17·99	14·37
Silt	8·55	9·45	5·00
Clay	13·06	12·79	23·76
Moisture	1·62	1·45	2·15
Loss on solution	1·33	1·27	0·94
$CaCO_3$	0·50	0·25	0
Loss on ignition	6·33	5·79	3·68
48 hours HCl Extraction			
Insoluble residue	82·46	83·24	80·54
Fe_2O_3	2·60	2·26	3·26
Al_2O_3	4·66	5·07	8·21
CaO	0·96	0·77	0·54
MgO	0·27	0·26	0·49
K_2O	0·39	0·37	0·53
P_2O_5	0·33	0·30	0·19
Nitrogen	0·21	0·19	0·07
Exchangeable CaO	0·40	0·39	0·41
pH	7·0	6·9	6·9

The Fen silts, being deep and moist, are among the most highly valued soils in the country. Their yielding powers are phenomenal, and since the spread of potato-growing and the introduction of horticultural crops into the area their treatment has become more and more intensive. Some four-fifths of the land is arable, with potatoes occupying approximately one-third of this area in each year. Wheat and sugar-beet also are important crops, whilst recently there has been a marked expansion in the growing of peas for canning, in addition to the already considerable

TABLE 4. *Analyses of Alluvial Soils (per cent.)*

Formation:	Fen silt		Fen peat		Marsh Alluvium	Alluvium	Valley Gravel				Brick-earth
County:	Holland	Norfolk	Hunts.	Ely	Norfolk	Essex	Beds.	Beds.	Cambs.	Suffolk	Essex
Locality:	Hundred Fen	Terrington	Holme	Manea	Ingham	Tillingham	Sandy	Sandy	Oakington	Mildenhall	Tillingham
Soil											
Coarse sand	0·1	0·4	0·6	11·8	0	11·2	49·7	35·9	52·0	65·1	22·2
Fine sand	61·8	42·2	1·2	18·0	35·5	16·0	24·1	27·9	22·5	27·8	31·4
Silt	12·8	26·0	3·0	16·7	15·7	25·7	9·6	13·3	7·7	3·4	19·0
Clay	14·1	20·7	17·3	12·8	8·1	33·8	7·8	12·5	10·8	0·4	16·6
$CaCO_3$	0·93	0·64	0·6	0	0·5	4·6	0·3	0·28	0·05	4·9	..
Organic matter	6·6	6·6	50·8	38·8	34·3	..	..	..	..	..	..
Subsoil											
Coarse sand	0·1	0·5	0·4	1·7	0	12·7	48·0	35·3	54·3	61·7	16·8
Fine sand	59·6	34·3	0·6	25·5	61·3	16·1	24·5	28·9	27·1	29·9	30·8
Silt	13·2	25·4	1·3	9·0	14·9	24·5	8·4	11·1	7·6	2·4	12·4
Clay	15·8	27·6	8·9	14·5	12·5	33·5	10·9	14·7	10·3	1·2	23·2
$CaCO_3$	4·8	2·7	0·17	0	0·04	7·3	0·27	1·6	0	..	..
Organic matter	4·6	6·5	62·2	55·2	5·1	..	..	..	..	..	..

acreage of peas grown for packeting or pulling green. Broccoli, cauliflower, and spring cabbage are also a feature of these soils, as well as root-crops and mustard grown for seed. Bulb-growing for the production of flowers has been practised for some time and in the last few years this industry has been extended considerably and now includes the production of bulbs themselves. In the southern part of the area the cultivation of fruit is extensively practised, the acreage of soft fruit having increased rapidly of late years to meet the demands of the recently established local canning factories. Live stock play little part in the agriculture of these silt lands. As in the case of the Fen peats, fattening cattle, kept to tread down the straw into manure, have recently become less popular, but a considerable number of pigs are kept.

The agricultural value of the Fen peaty soils depends largely on two factors, (1) an efficient drainage-system—the water being raised by pumps from the field dykes into the main water-courses, (2) the depth of the peat-layer and the nature of the underlying mineral material. Where a bed of what is locally termed 'blue buttery clay' is to be found within a few feet of the surface, this material can be excavated from trenches across the fields and spread on the surface, thereby improving the texture and cropping powers of the land. Almost all the best black fenland has been 'clayed' in this way in the past and the process requires to be repeated, though at fairly long intervals, if the cropping power of the land is to be maintained. Almost the whole of the Fen peat area is arable; potatoes, sugar-beet, wheat, and barley are the principal crops, and though the quality of the produce is not of the best, the heavy yields more than compensate for this. Appreciable acreages of carrots, mustard seed, rape or 'cole' seed, and celery are also grown. Live stock are of little importance in these districts; formerly, bullocks were fattened in yards primarily to tread down the large quantities of straw, but in recent years there has been a tendency to replace bullocks by pigs, though the latter are still often regarded as a necessary evil rather than a desirable side-line. Where the peat layer is too thick or the underlying mineral material is not suitable for mixing with the top peat, these soils are much less valuable.

In view of the favourable situation of the Valley and River Gravels, it is not surprising that many of them are to a large extent devoted to market-gardening. The valley gravels of Bedfordshire and SE. Essex have for many years supplied vegetables to the chief markets of London and the Midlands. At the same time, it has been possible to return to these soils vast quantities of town dung, which has served to build up in them reserves of organic matter and plant-food sufficient to lift them to an entirely different level of fertility. They are devoted almost exclusively to the production of potatoes and vegetable crops, cereals being grown only when it is desired to rest the land. In Cambridgeshire the intensive cultivation of these gravels has developed more along the lines of fruit- and flower-culture, vegetable-growing being less popular. Live stock and permanent grassland are almost unknown on most holdings and play little part in the agriculture of the district.

Soils of the Chalk.—The Chalk comes next in importance from the point of view of the area of land concerned. Though it underlies approxi-

mately one-third of the whole area, it outcrops over a comparatively small portion of it, between the main Boulder Clay mass in the east, and the Fens and Lower Cretaceous areas on the west. The basement beds of the Upper, Middle, and Lower Chalks are frequently marked by escarpments, so that they, with the Chalk Marl, in general constitute a succession of terraces along the length of the outcrop. Superimposed on this outcrop there are, in various localities, outliers of the Boulder Clay, patches of Valley Gravel, Old River Gravel, Glacial Gravel, and Clay with Flints. Considerable areas, especially in Norfolk and Suffolk, are covered by a layer of coarse sand. The terms 'whitelands' and 'redlands', used locally, serve to indicate one method of classification. The former include soils which largely consist of chalk and in which the solid chalk, or in some cases disturbed chalk, lies within a few inches of the surface. Such soils occur throughout the four main divisions of the Chalk formation. Over considerable stretches of SE. Cambridgeshire are to be found 'redlands' consisting of light sandy loams, slightly stony and of varying depth, lying on the Middle Chalk. Throughout this area patches of the older gravels are frequent and there is a great similarity between the soils on them and those on the surrounding chalk exposures. The chalk in NW. Suffolk and in Norfolk is covered by even coarser and more open sands, associated with the characteristic heaths and woods of these parts. In Hertfordshire, where expanses of Clay with Flints are common, yet another type of soil material is to be found.

The constitution of some of these types of chalk soils is indicated in Table 5.

TABLE 5. *Analyses of Chalk Soils (per cent.)*

Type:	Whitelands	Whitelands	Redlands	Sand on Chalk
Formation:	Chalk Marl	Middle Chalk	Middle Chalk	Middle Chalk
County:	Cambs.	Cambs.	Cambs.	Suffolk
Locality:	Litlington	Heydon	Ickleton	Brandon
Soil				
Coarse sand .	5·0	9·3	39·3	59·7
Fine sand .	10·7	18·4	20·1	35·8
Silt . .	15·4	24·6	9·1	0·7
Clay . .	20·0	9·3	10·4	0·3
$CaCO_3$ . .	29·3	59·5	13·3	0·07
Subsoil				
Coarse sand .	3·0	Chalk	38·4	71·2
Fine sand .	10·7	..	20·0	26·0
Silt . .	15·1	..	9·3	0·5
Clay . .	19·4	..	10·6	0·6
$CaCO_3$ . .	36·4	..	16·7	..

The soils overlying the chalk-formation are almost exclusively devoted to extensive arable farming. Some four-fifths of the land is under the plough, except in the case of sand on chalk, where the proportion of arable is rather less. The principal crops are barley (for malting), sugar-beet, and green crops for folding by sheep. In addition, a considerable

acreage of wheat is grown and many of these soils, particularly the 'white-lands' in Cambridgeshire, are noted for the production of the seed of leguminous crops. Though live stock in general are a relatively unimportant feature of the agriculture of these districts, sheep are regarded by many farmers as an essential part of their farming policy. The folding of green crops and seeds-leys by sheep is the chief means of maintaining these soils in a reasonably fertile condition, especially in the case of the lighter textured sands on chalk, though the ploughing in of green crops as 'green manure' is also a common practice, especially on the 'white-lands'. Fattening-cattle have become less conspicuous in these districts in recent years, but a good number of pigs are kept. The lightest of the sand-on-chalk soils are uncultivated, giving rise to wide expanses of heath, appreciable areas of which are planted with forest trees.

Soils of the Clay-Formations.—Besides the Boulder Clay, there are in this part of England other considerable localized areas in which the parent material is clay. Examples of typical soils on these formations are given in Table 6.

TABLE 6. *Analyses of Clay Soils (other than Boulder Clay (per cent.)*

Formation:	Clay with Flints	London Clay	London Clay	Gault	Kimeridge Clay	Oxford Clay	Lias Clay
County:	Herts.	Essex	Essex	Cambs.	Cambs.	Hunts.	Kesteven
Locality:	Weston	Rettendon	Havering	Cambridge	Lolworth	Holywell	Sedgbrook
Soil							
Coarse sand	28·1	19·9	2·2	3·9	20·0	9·7	10·1
Fine sand .	18·6	24·7	48·0	7·4	24·4	17·0	14·0
Silt . .	13·0	25·2	17·5	17·7	15·8	17·7	29·6
Clay . .	25·8	31·2	20·3	61·1	34·0	35·8	29·1
$CaCO_3$.	0·46	0·17	1·85	7·9	0	0·92	0·06
Subsoil							
Coarse sand	23·9	18·8	0·3	2·9	20·6	8·7	10·6
Fine sand .	15·4	23·9	27·4	6·8	22·3	17·4	12·3
Silt . .	9·9	20·1	16·5	17·5	16·8	16·9	26·4
Clay . .	35·5	40·8	42·2	61·1	39·4	38·6	37·2
$CaCO_3$.	0·57	0·01	0·06	10·1	0	1·7	0·02

The Clay with Flints occurs on the crests and higher slopes of the exposures of the Chalk in Hertfordshire. It consists of stiff red clay, reddish-brown loamy clay, and reddish-brown sandy clay, associated with flints and pebbles. Its origin is doubtful, and particularly whether it is a derivative of the Chalk or of more recent Eocene deposits. In the main, the surface soils vary from light to heavy loams, lying on much stiffer subsoils, frequently clay. Many of the soils examined are of very low chalk-content.

The London Clay covers a considerable area of the lowlands of SE. Essex and of S. Hertfordshire. It consists essentially of stiff blue or dark brown clay weathering to a much richer brown or yellow at the surface. The soils are heavy, varying from clays to medium loams, on markedly heavier subsoils. The chalk-content is low, nearly always less than 1 per cent.

The Gault gives rise to some of the heaviest land in the country, in a strip lying at the base of the Chalk escarpment in Bedfordshire and

Cambridgeshire. The elevation of the area is very slight and general drainage conditions are poor. In its ordinary winter condition the soil is impervious except in the tilled layer, and standing water on the surface is a common occurrence except where under-drainage has been carried out. In summer, on the other hand, drying out and fissuring occur to a considerable depth, in dry years to as much as 5 ft. The general nature of the profile is indicated in Table 7.

TABLE 7. *Analyses of a Gault Soil Profile (per cent.)*

	0–30 in. Yellowish-grey heavy clay	*30–44 in. Blue-grey clay with orange mottling*	*44–66 in. Blue-grey clay with mottling and white crystalline pockets*	*66 in.+ Blue-grey clay*
A.E.A. method 1927				
Coarse sand	3·9	2·9	0·02	0·03
Fine sand	7·4	6·8	0·2	0·2
Silt	17·7	17·5	11·4	12·5
Clay	61·1	61·1	51·6	52·2
Moisture	5·8	6·0	4·1	3·7
Loss on solution	1·5	1·5	1·0	0·8
$CaCO_3$	7·9	10·1	35·1	36·2
Loss on ignition (less CO_2)	9·9	8·1	5·3	6·1
Nitrogen	0·19	0·13	0·04	0·04
Exchangeable CaO	0·89	0·89	0·99	0·37
48 hours HCl Extract				
Insol. residue	52·8	51·5	32·72	33·43
Fe_2O_3	4·32	4·80	2·96	3·08
Al_2O_3	15·91	16·03	14·89	14·13
CaO	5·27	6·21	20·16	20·75
MgO	0·97	0·90	1·03	0·82
K_2O	1·40	1·44	1·44	1·44
P_2O_5	0·15	0·15	0·13	0·08
SO_3	..	..	1·9	0·17

Actually, considerable variations are found within the horizons set out in Table 7. Thus the surface soil rapidly changes from dark grey-brown at the surface to yellowish-grey at a depth of 5–9 in. On grassland the amount of organic matter in a typical sample fell from 12 per cent. in the first inch to 3 per cent. at a depth of 6 in. and 2 per cent. at 12 in. The percentage of calcium carbonate at the surface was 3 per cent., at 12 in. 4 per cent., at 24 in. 18 per cent., and at 36 in. 39 per cent.

The Kimeridge Clay appears for the most part as island outcrops in the general Fen area, associated with low-lying and flat land. In contrast with the Gault, this material is non-calcareous, but exhibits similar mottling in the subsoil. Details of a characteristic profile are given in Table 8.

The Oxford Clay is the parent material of much heavy land in the north of Bedfordshire, in Huntingdonshire, and Kesteven. It consists

TABLE 8. *Analyses of a Profile of a Kimeridge Clay Soil (per cent.)*

	0–9 in. Grey-brown heavy loam	*9–13 in. Light-brown transition layer*	*13–27 in. Light-brown clay, with orange mottling*	*27–34 in. Grey-brown clay, with mottling*	*34 in.+ Grey clay with much coarse crystalline calcium sulphate*
A.E.A. method 1927					
Coarse sand	20·0	20·6	14·2	7·2	0·1
Fine sand	24·4	22·3	20·3	6·6	2·7
Silt	15·8	16·8	17·0	18·1	7·7
Clay	34·0	39·4	48·0	60·5	40·9
Moisture	2·9	3·6	4·0	4·3	6·5
Loss on solution	1·16	0·94	0·73	1·02	0·99
$CaCO_3$	..	..	..	8·8	13·2
Loss on ignition (less CO_2)	6·55	5·35	5·60	6·13	5·79
48 hours HCl Extract					
Insol. residue	75·15	73·99	70·33	56·86	36·55
Fe_2O_3	8·40	8·08	9·84	8·72	4·32
Al_2O_3	3·94	4·64	6·22	9·83	9·03
CaO	0·65	0·74	0·76	5·39	15·49
MgO	0·58	0·63	0·84	1·07	0·98
K_2O	0·96	1·10	1·32	1·95	1·53
P_2O_5	0·16	0·17	0·09	0·09	0·16
SO_3	0·33	0·34	0·29	0·64	12·30
Nitrogen	0·19	0·11	0·07	0·06	0·04
Exch. CaO	0·54	0·52	0·52	0·51	0·22

of grey-blue clay, which weathers to a creamy or brown colour. The profile shows similar trends to those of the Gault and Kimeridge Clay soils in the transition of colour from surface to depth, and in the occurrence of mottling and accumulation of crystalline material in certain horizons. The soils are all clays or heavy clay loams with, as a rule, a calcium-carbonate content up to 3–4 per cent.

The Lias Clay in this province is confined to the west of Kesteven, where it gives rise to soils varying from heavy clays to medium loams with a small calcium-carbonate content.

The agriculture of these clay-formations differs considerably from that of other formations in the province. After the Boulder Clay, the London Clay is probably the most important clay-formation in the area. The soil is heavy, but its proximity to London and other large consuming centres gives it very definite advantages in the disposal of its agricultural produce. Nearly three-quarters of the London Clay is under permanent grass with live stock and milk-production the outstanding features of the agriculture of the area. Poultry, feeding-cattle, and grass-sheep find a place in the farming of this district, but pigs are not kept to any great extent. The small proportion of land under arable cultivation is devoted largely to potatoes and market-garden crops. Wheat, barley, and sugar-beet, so important a feature of the agriculture of the Boulder Clay, are comparatively unimportant on the London Clay soils.

The Gault, Oxford, and Kimeridge Clays give rise to heavy soils which are, for the most part, typical wheat and bean land. Bare fallows are taken more frequently than on any other soil types in the province. If the difficulties of natural drainage can be overcome and the land be liberally treated with phosphates, these clays will usually carry quite good permanent grass. When corn prices are good, a fair proportion of these

clay soils is kept under the plough, but when cereals become unremunerative, considerable areas are either sown down, or allowed to tumble down to grass. Live stock are not a prominent feature of the agriculture of these areas. A little dairying is practised locally, but feeding-cattle are the most common type of stock, though grassland sheep have increased in importance in recent years.

Soils of the Lower Greensand.—A small but important area of the region is occupied by soils derived from the Lower Greensand. This formation outcrops in an interrupted belt through Bedfordshire, Cambridgeshire, and W. Norfolk. It consists for the most part of coarse sands or sandstones, giving rise to soils, rich brown or reddish-brown in colour, and coarse sands or loamy sands in texture. Except where they have been limed, they are as a rule acid.

From the agricultural standpoint the Lower Greensand soils fall into three main groups, (1) the light sandy soils favourably situated as regards transport and markets, (2) soils of similar or lighter texture but less favourably situated, (3) loamy sands. Near the edge of the outcrop, where the Greensand becomes mixed with Kimeridge or Gault clay, a heavier textured soil is found. The light sandy soils constitute the typical early market-garden land of Bedfordshire, and are used almost exclusively for the production of early potatoes and vegetables when they are within easy reach of good markets. The very lightest of these soils are frequently left as heaths or woodlands. The loamy sands and loams make good fruit soils and the Cambridgeshire area carries a high proportion of mixed fruit.

For further detailed information on the soils and agriculture of this province, reference may be made to the following publications:

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WOOL-GROWTH IN SHEEP AS AFFECTED BY THE CARBOHYDRATE-CONTENT OF THE DIET. II

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Introduction.—In a previous experiment [1] we showed that a starch supplement fed to sheep under certain conditions produced a significant increase in both body-weight and gross fleece-weight. The increase in gross fleece-weight was reflected in the weight of clean wool, the increased yield being due to a definite increase in fibre-thickness, a slight increase in fibre-length, and possibly also to an increase in the proportion of follicles actively elaborating fibres. In that experiment one group of ten growing sheep was fed a maintenance ration, while a second group of ten was fed the same ration supplemented with maize starch.

At the end of the experiment the group fed on the maintenance ration was divided into two sub-groups of five sheep. One sub-group was again fed a maintenance ration while the second was fed the same ration supplemented with maize starch. The results of feeding the starch supplement to sheep after a period of arrested growth are recorded in the present communication.

Experimental Results

Duration and food consumption.—The experiment began on June 12, 1933, and continued until September 18, 1933—a period of 98 days. The food-consumption during that period is shown in Table 1.

TABLE 1. *Foods consumed June 12–Sept. 18, 1933*

Food	*Group I (maintenance)*		*Group II (maintenance+maize starch)*	
	Total lb.	*Per sheep lb.*	*Total lb.*	*Per sheep lb.*
Potatoes	897	179	897	179
Meals[1]	219	44	219	44
Oat straw	252	50	252	50
Starch	0	0	489	98
Water and salt (NaCl)	ad lib.	ad lib.	ad lib.	ad lib.

[1] Composition of Meal: (1) Linseed-cake meal. (2) Chalk, 2·2 per cent. of (1). (3) Cod-liver oil, $2\frac{1}{2}$ c.c. per head daily.

The only dietary difference between the two groups was that Group II

received a supplement of 489 lb. of maize starch, or a total of 98 lb. per head, during the 98-day period of the experiment.

Body-weight.—The effects of this supplement on body-weight are shown in Fig. 1. It is seen that whilst the initial mean weights of the two groups were almost equal, the final weights at the end of the experiment were significantly different, the final mean weight of Group I being 67 lb., that of Group II 86 lb., the mean difference between the two groups being therefore 19 lb.

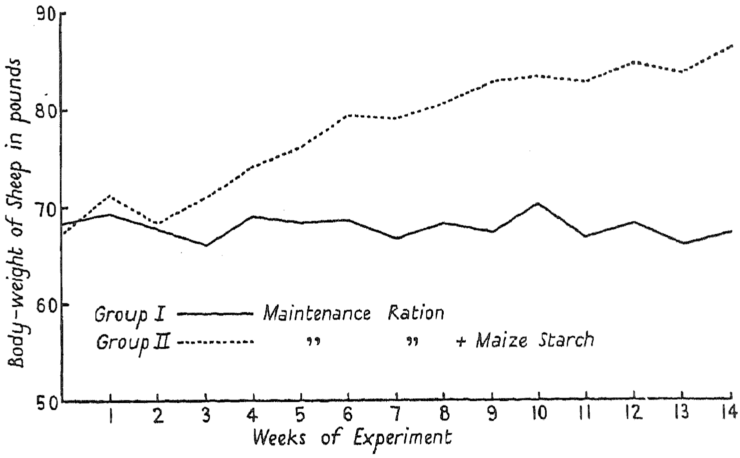

FIG. 1. Body-weight of Sheep in pounds.

Wool-analyses.—The sheep were sampled on September 18, 1933, the wool on the areas defined by tattooing, at the outset of the previous (winter) experiment [1], being carefully separated from the contiguous staples, and removed. These samples were compared with those taken on May 24, at the end of the first experiment. The wool on the defined areas represented 117 days' growth, compared with 169 days previously. Shearing took place on September 19, the fleece-weights recorded being those resulting from 117 days' growth (the comparison in this case being with the earlier period of 161 days) [1].

From May 25, 1933, all the animals were maintained upon the basal ration; the administration of the starch supplement to Group II started on June 12, and continued until September 18, thus the nutritional difference between the Groups was carried on for a period of 98 days. The conditions of growth of the fleeces of Group II consisted in 19 days on basal ration and 98 days of starch supplement, and those of Group I, 117 days on basal ration, following upon 161 days of basal-ration feeding in both groups.

The methods of analysis were the same as those employed previously [1], and the results are expressed in the form of a percentage change upon the conditions at the beginning of the experiment.

(*a*) *Fleece-weights.*—The average fleece-weight of the group receiving the starch supplement was about $2\frac{1}{2}$ times that of the basal-ration group (Table 2). These weights do not reveal the effects of the ration on actual

wool-production, but estimates of the amounts of clean wool grown can be made, assuming that the area samples are representative of the whole fleeces in respect of clean-wool yield. These estimates are given in Table 3.

TABLE 2. *Fleece-weights (in grammes)*

Group I				Group II			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	494	415	−16·0	5	305	880	+188·5
3	304	340	+11·8	11	534	730	+ 36·7
7	605	595	− 1·7	15	302	775	+156·6
9	524	335	−36·1	17	648	1,140	+ 75·9
13	223	135	−39·5	20	662	1,145	+ 73·0
Mean	430	364	−16·3	..	490·2	934	+106·1
S.E.	±71·51	±74·11	±9·84	..	±79·38	±88·55	±28·44

Difference of Means: Pre-experimental: 60·2±106·8
" " Experimental: 570±115·4
" " Percentage change: 122·4±30·09

TABLE 3. *Sample Yield and Estimated Weight of Clean Fleece (gm.)*

Group I					Group II				
	Pre-experimental		*Experimental*			*Pre-experimental*		*Experimental*	
Animal	*Sample yield per cent.*[1]	*Estmd. clean fleece-weight*	*Sample yield per*[1] *cent.*	*Estmd. clean fleece-weight*	*Animal*	*Sample yield per cent.*[1]	*Estmd. clean fleece-weight*	*Sample yield per cent.*[1]	*Estmd. clean fleece-weight*
1	74·5	368	73·6	305	5	68·3	208	49·2	433
3	66·9	203	72·4	246	11	72·2	386	65·1	475
7	75·9	459	75·5	449	15	62·4	188	48·7	377
9	70·2	368	75·4	253	17	69·6	451	64·3	733
13	66·5	148	69·2	93	20	73·3	485	62·0	710
Mean	70·8	309·2	73·8	269·2		69·2	343·6	57·9	545·6

[1] Clean, dry wool as percentage of raw (greasy) wool.

On this basis, although the difference between the groups is not so wide as in the greasy fleece-weight, the effect of the starch supplement in raising the level of production is clearly shown.

(*b*) *Area samples.*—The clean dry weights of wool grown on the tattooed areas are given in Table 4. The difference between the two groups was insignificant prior to this experiment, but that at the end of the 117-day period demonstrates the advantageous effect of the starch supplement, which may be credited with leading to an increased production of 47 per cent.

(*c*) *Mean fibre-length.*—The mean fibre-lengths were determined by the method of Roberts [2], the area samples each being divided into eight zones, and the proportion of fibres measured being one in eight, except

in two cases where it was one in six and one in nine. The numbers of 'short' fibres present were small and they made little contribution to the total lengths measured. Table 5 shows that the character of mean fibre-length underwent no significant change under the experimental conditions; the difference in production therefore must lie chiefly in the response of fibre-fineness to the altered nutritional level. In this respect, the present results confirm those of the earlier experiment.

TABLE 4. *Clean-Dry Weights of Area Samples (in gm.)*

Group I				*Group II*			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	1·84	1·53	−16·9	5	1·57	2·24	+42·7
3	0·93	1·31	+40·9	11	1·53	1·51	− 1·3
7	1·83	2·03	+10·9	15	1·23	2·06	+67·5
9	1·25	1·35	+ 8·0	17	1·35	2·18	+61·5
13	1·03	0·45	−56·3	20	1·78	2·71	+52·3
Mean	1·38	1·33	− 2·7		1·49	2·14	+44·5
S.E.	±0·19	±0·26	±16·2		±0·09	±0·19	±12·2

Difference of Means: Pre-experimental: 0·11
,, ,, Experimental: 0·81±0·32
,, ,, Percentage change: 47·2±20·3

TABLE 5. *Mean Fibre-lengths (in cm.) including Short Fibres*

Group I				*Group II*			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	5·55	4·4	−20·7	5	5·9	5·1	−13·6
3	3·7	4·7	+27·0	11	5·9	4·5	−23·7
7	6·3	5·1	−19·1	15	4·4	4·4	. .
9	5·8	4·0	−31·0	17	5·6	5·3	−5·4
13	3·8	1·2	−68·4	20	6·0	4·9	−18·3
Mean	5·03	3·88	−22·4		5·56	4·84	−12·2
S.E.	±0·53	±0·69	±15·25		±0·29	±0·16	±4·29

Difference of Means: Pre-experimental: 0·53±0·61.
,, ,, Experimental: 0·96±0·71.
,, ,, Percentage change: 10·2±15·8.

(*d*) *Average fineness.*—Fibre-growth during this period was coarser than that of the winter experiment; and although the differences between the pre-experimental and experimental group means are not significant, the Group percentage changes show that a real alteration in this character occurred.

A differential response as between the characters of mean fibre-length and average fineness is again manifested, the change in fineness of Group II outweighing the changes in length and growth-rate.

TABLE 6. *Average Fineness (cm./mgm.)*

Group I				Group II			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	167·3	185	+10·6	5	159	124	−22·0
3	206	166	−19·4	11	124	100	−19·4
7	163·5	139	−15·0	15	281	205	−27·1
9	191	160	−16·2	17	159	93	−41·5
13	175	133	−24·0	20	133	85	−36·1
Mean	180·6	156·6	−12·8		171·2	121·4	−29·2
S.E.	±7·92	±9·41	± 6·05		±28·32	±21·89	±4·20

Difference of Means: Pre-experimental: 9·4±29·4.
,, ,, Experimental: 35·2±23·8.
,, ,, Percentage change: 16·4±7·37.

Summary and Conclusions

In a previous communication [1], we showed that when starch is added to the maintenance ration of young Cheviot sheep, significant increases in fleece-weight and body-weight result, and that the increase in fleece-weight is mainly attributable to an increased diameter of the wool-fibres.

The present communication provides further confirmation of these findings. The maintenance group of ten sheep was divided into two sub-groups of five. One sub-group continued to receive a maintenance ration for a further period of 117 days, during which they grew wool at the rate of 2·3 gm. per sheep per day as compared with 1·9 gm. per day during the earlier experiment. The second sub-group during 98 days of the second experimental period of 117 days received 98 lb. of starch per head in addition to the basal ration, and produced wool at the rate of 4·7 gm. per day, compared with 2·1 gm. in the earlier experiment.

The addition of 1 lb. of maize starch per day to the maintenance diet of these growing Cheviot sheep, therefore, doubled their wool-production, and the increase was chiefly due to the greater thickness of the individual wool-fibres.

The two experiments taken together show that although wool-fibre is a protein substance, nevertheless under certain conditions its growth may be profoundly influenced by the carbohydrate in the sheep's diet.

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CARCASS QUALITY OF THE PIG IN RELATION TO GROWTH AND DIET

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WITH PLATES 8, 9 AND 10

Growth and conformation.—Pigs, like other mammals, have three main phases of growth. During the first phase, the skeleton grows more rapidly than at any later period. During the second phase, muscular growth predominates. This is followed by a phase during which the rate

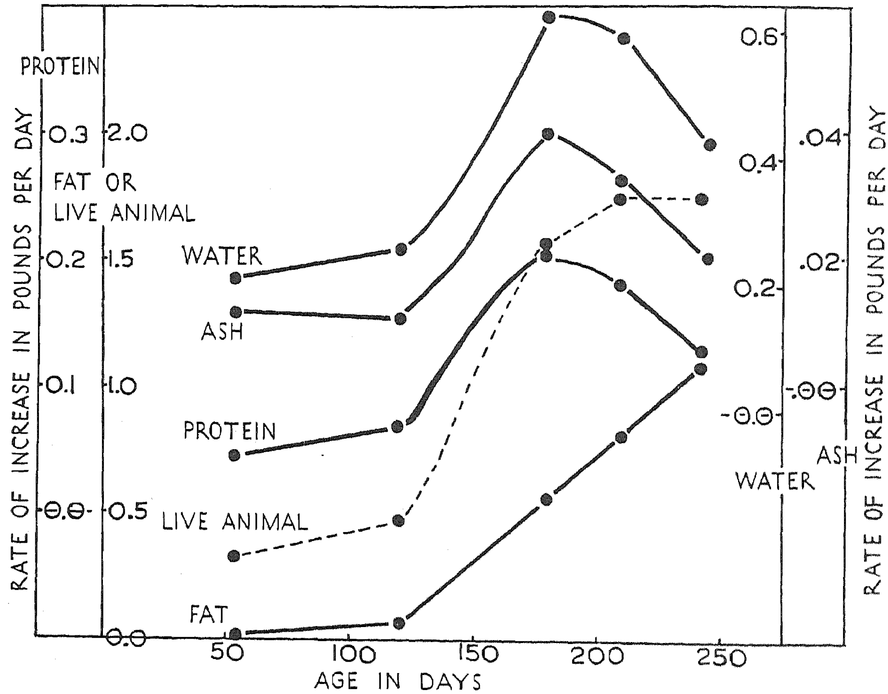

FIG. 1. The relation between the growth-rate of the pig at various ages and the rate of increase of the water, ash, protein, and fat of the carcass at corresponding ages. The data used in constructing these curves were calculated from figures given by Ellis and Hankins (1925).

of deposition of fat reaches a maximum; fat is deposited between and in the muscles, and the animal becomes mature and finally overfat (see Fig. 1). All these phases of growth appear to start at the head and travel gradually to the tail, and the shape of the body thus undergoes progressive changes. At birth, the pig has a relatively large head and a short body. As the animal grows older, the head becomes relatively smaller and the body relatively longer [44]. At the same time, the growing tissues exhibit progressive alterations in chemical composition [94]. The

bones gradually get harder and the water-content of all the tissues gradually decreases. The muscles become more pigmented with age and exercise, owing to an increase in their content of haemoglobin. The concentration of extractives also increases, and this gives the resultant meat a more marked flavour. As the animal ages, the quantity of fat deposited in the tissues increases. It is first of all deposited in the subcutaneous tissues and around the kidneys (flare fat), stomach, and intestines. As the animal becomes mature, the back fat increases in

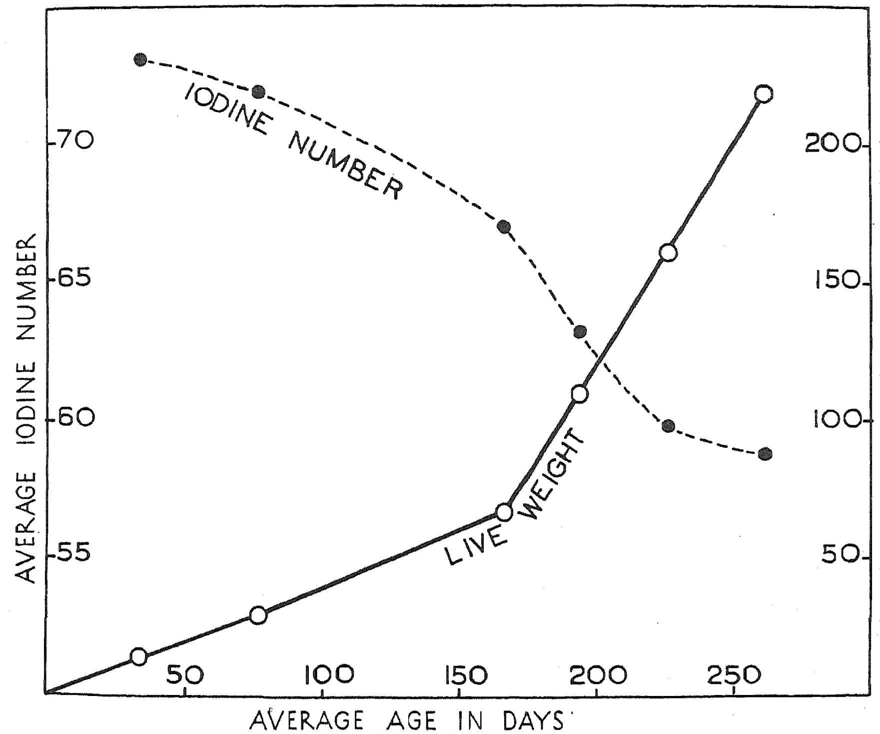

FIG. 2. The relation between age, live-weight, and the iodine number of the fat. These curves have been constructed from data given by Ellis and Hankins (1925).

thickness and fat is laid down between and in the muscles. It is this inter- and intra-muscular fat, especially in the abdominal muscles, that is responsible for the 'finish' of the resultant carcass. Besides increasing in quantity, the fat also improves in quality as the pig grows older. The fat of young pigs contains a higher proportion of unsaturated fatty acids and is therefore relatively soft. As the pig grows older, the fat becomes more saturated and consequently harder. This fat has a lower iodine number and a lower refractive index than the softer fat from younger pigs [26, 49, 75, 115, 119] (see Fig. 2 and Table 1).

Although growth follows the same general course in all types of pig, there are considerable differences in the various breeds and strains. In the Middle White breed, the pig is ready for the pork market at the age

of $4\frac{1}{2}$ months when it has reached only 100 lb. live-weight. If it is allowed to reach bacon-weight (200 lb. live-weight), it is decidedly over-fat and lacks length for its weight. On the other hand, a Large White pig gives an excellent bacon carcass at 200 lb. live-weight, by which time it is about $6\frac{1}{2}$ months old [45]. If a Large White pig is killed for pork at 100 lb. live-weight, the carcass is apt to be immature and 'unfinished',

TABLE 1. *Alteration of Fatty Tissue (Back fat) with Age*

(From Scott, 1930)

Thickness of back fat	*Refractive index of extracted fat*	*Percentage of fat*	*Percentage of moisture*	*Percentage of protein*
1·9 cm.	1·4606	91·33	6·37	1·76
4·7 ,,	1·4597	94·20	1·79	1·21

the meat too lean and the flank too thin. The fat tends to be soft and the proportion of bone may be too high. Davidson [17], however, has shown that this is not necessarily so, as with appropriate feeding the Large White breed can give very good pork carcasses at 100 lb. live-weight. The age at which bacon-weight is reached is also influenced to some extent by sex. Gilts tend to grow rather more slowly than hogs [17, 115], and therefore, at bacon-weight (200 lb. live-weight), hogs are usually more mature than gilts and have a thicker layer of back fat [99].

The small type of pig which matures at a comparatively low weight appears to have a slower rate of growth than the longer type of pig which matures later in life and provides a heavier carcass (see Table 2).

TABLE 2. *Data showing the Average Time taken by Various Breeds to reach Certain Live-weights*

(From Whetham, 1934–5)

	Short type		*Long type*		
Live-weight	*Middle White*	*Berkshire*	*Large White*	*Bacon pigs*	*Crossbred*
lb.	days	days	days	days	days
75	118·8	108·5	108·4	104·3	111·9
100	137·0	132·1	126·1	124·3	130·0
125	155·2	155·7	143·9	146·0	148·2
150	173·4	179·3	161·6	164·0	166·4
175	191·6	202·9	179·4	180·0	184·5
200	209·8	226·5	197·1	197·0	202·7
225	228·0	250·1	214·9	211·0	220·9
250	246·2	273·7	232·6	227·0	239·1

The figures for Middle White, Berkshire, Large White, and Crossbred pigs are average figures from the records of the Smithfield Show carcass-competitions for the years 1914 to 1933, except for 1917 and 1918, when no shows were held. The results include data from 1,067 pigs.

The results for bacon pigs are taken from Table 4 of the Second Report of the East Anglian Pig-recording Scheme [24] and are average figures calculated from a variety of sources.

Even with the heavy-carcass class of pig, there is some evidence that faster rates of growth are associated with extra length of carcass. Thus Scott [115], working in America with over 600 pigs from 8 different breeds, showed that the longer type of pig had a higher rate of growth and produced heavier carcasses than the shorter type of pig (see Table 3).

TABLE 3. *Growth-rate and Length of Carcass*

(From Scott, 1930)

Type	*Number of hogs*	*Average length*[1]	*Average live-weight*	*Average daily gain*
Medium Plus	135	137·8 cm.	225·2 lb.	1·22±0·007 lb.
Medium	397	128·9 ,,	201·8 ,,	1·09±0·004 ,,
Medium Minus	127	118·9 ,,	187·1 ,,	0·96±0·006 ,,

[1] The carcasses were measured from the front rib to the aitch bone and from the aitch bone to the toe of the hind leg. These two measurements were added together for 'length'.

Hansson [52], working in Sweden, obtained similar results. Results from the Iowa Agricultural Experimental Station [69] also showed that the 'big' type of pig made more rapid gains than the medium type. Callow and Davidson [11], working with a more homogeneous group of pigs (27 pigs from 11 sows by one boar in a pedigree Large White herd), also found that the long type of pig had a faster growth-rate than the short type (see Table 4). Hansson and Bengtsson [53] found that the long type of pig has less back fat and a more even distribution of fat than the short type of pig. The short type tends to be overfat, especially over the shoulders. Callow and Davidson also found that the short type tended to be somewhat overfat at bacon-weight, as shown by the extra amount of fat laid down in the muscles and by the extra thickness of flank (see Table 4). In addition, their results for the *psoas* muscle (fillet

TABLE 4. *Growth-rate and Length in Bacon Pigs*

(Callow and Davidson; unpublished results)

Average growth-rate lb. per day	*Average length*	*Average weight of* psoas *muscle*	*Percentage of fat in* psoas	*Percentage of water in* psoas	*Average thickness of flank*
0·56	75·2 cm.	182·6 gm.	3·2	73·7	3·2 cm.
0·62	76·8 ,,	201·0 ,,	2·5	74·9	2·4 ,,
0·70	77·7 ,,	218·1 ,,	2·0	75·0	2·1 ,,

The results in each case are the average for 9 pigs. The growth-rate was obtained by dividing the dead-weight of the carcass in pounds by the age of the pig in days. The length was measured from the aitch bone to the front rib. The *psoas* muscle was obtained by removing the fillet, and trimming it free from visible fat.

or undercut) suggest that the short type of Large White pig may have a less highly developed muscular system and would thus yield less lean meat than the long type, which grows more rapidly [11]. It appears possible,

however, to obtain a short type of pig, such as the Berkshire, which has a very well-developed muscular system (see Plate 8).

The idea that a rapid rate of growth is associated with the longer type of body is not entirely supported by the work of Carroll and his co-workers [14]. These investigators showed that the short 'chuffy' type of Poland China pig undoubtedly had a slower rate of growth than the longer 'intermediate' type. On the other hand, the longest 'rangy' type had a lower rate of growth than the 'intermediate' type. Hogan, Weaver, Edinger, and Trowbridge [66] found no significant difference between the growth-rates of long and short pigs. They used 8 pigs of the Large Yorkshire breed and 8 of the 'big' type of Poland China pigs. The Large Yorkshire pigs were consistently longer, and continued to grow in length for a longer period than the Poland China pigs, but the average growth-rates were practically identical. Evvard [33], using the self-feeding method for the fattening of pigs, actually obtained the greatest rate of growth with the small type of pig and the slowest rate with the large type.

Effect of diet.—Work on growth-rates, however, is complicated by the fact that an alteration in the diet of the pig may have a profound effect on the rate of growth. For example, Clausen [15] records that pigs grew from 20 to 90 kg. in weight in 112 days when the diet contained a high proportion of skimmed milk, but took 124 days when half the milk was replaced by a mixture of blood, bone, and meat meals, and 132 days when all the skimmed milk was replaced by the mixture. Unfortunately, no measurements of carcass are given in Clausen's paper. Various workers [37, 62, 63, 94] have shown that it is possible to keep the weight of a growing pig practically constant by giving it a subnormal diet. Under these conditions, growth is not entirely prevented. There is an appreciable growth of bone and a slight growth of muscle, but the fat-content of the body progressively diminishes. Henseler [63] found that a pig kept for some time on a subnormal diet weighed only 20·8 per cent. of the control pig on a normal diet, but its growth in length had not been affected to the same extent (see Table 5). The full effects of such subnormal diets are not yet known in the case of the pig, but with beef

TABLE 5. *The Effect of a Subnormal Diet on the Pig*

(From Henseler, 1914)

	Weight of pig	*Length*
Normal diet	127 kg.	193 cm.
Subnormal diet	26·5 kg. (20·8 per cent.)	145 cm. (75·1 per cent.)

animals Moulton [97] has shown that extensive changes occur in the chemical composition of the muscles, blood, and liver. In addition he showed that muscle-fibres became smaller in diameter but still continued to function. Hoagland and Powick [64] have shown that the flesh of extremely emaciated cattle is characterized by a relatively high moisture-content and by low contents of fat and protein. The work of Mitchell and Hamilton [94] suggests that pigs on maintenance diets are affected in a somewhat similar way. When pigs on subnormal diets are again

allowed full rations, there is a rapid increase in weight [13], and the rate of growth may be greater than the normal. The gain in weight per pound of food consumed also tends to be greater than the normal. The use of subnormal diets (e.g. during a store period), however, is to be deprecated, as the slowing down of the growth of the pig during its early life adversely affects the formation of bone and, to an even greater extent, that of muscle [47].

The effect of diet on growth and carcass-conformation has for its logical starting-point the pre-natal life of the pig. Unless pregnant sows receive adequate diets, their offspring will not yield carcasses with ideal conformation. The importance of having large and vigorous pigs at birth has been emphasized by a study of the data from 1,430 pigs in the U.S.A. It was found that the heavier the young pig when born, the greater was the percentage which survived to weaning and the more rapid were the gains made up to 6 months [95]. The pregnant sow needs a diet relatively high in protein, and adequately supplied with mineral salts [34, 41, 117] and other accessory food factors. Animal proteins are probably better than vegetable ones [76, 81, 123] and milk proteins are the best of all [56, 57, 71, 81, 114, 120, 123]. If a large proportion of vegetable protein is used, extra calcium is needed and extra salt should be included in the diet in order that the protein may be utilized in the most efficient manner [47, 92]. Indoor management is to be deprecated [65, 88, 122] as it increases the difficulty of supplying accessory food factors and mineral salts. Even when the sow has access to grazing, there may still be deficiencies in the diet if the land itself is deficient. Occasionally, cases of iodine deficiency have been recorded [121], and calcium deficiencies are fairly common. Orr and Davidson [103] have shown that a long continued deficiency of calcium in the diet leads to a progressive increase in the number of dead pigs in a litter, each generation becoming worse in this respect. In four generations the mortality increased from 4·8 to 50 per cent. per litter. The pregnant sow not only needs calcium salts but also additional supplies of iron and copper salts because, during development, the embryo should store up enough iron and copper (mainly in the liver) to last the young pig throughout the entire suckling period. The best source of iron and copper is grass or green foodstuffs. Various workers recommend the direct addition of salts of iron and copper to the diet of the pregnant sow, but Husby [68] found that this increased the number of pigs which were born dead or died during suckling.

The lactating sow, like the pregnant sow, would appear to need a diet that is relatively high in protein and contains adequate supplies of mineral salts and accessory food factors. There may be 10 or more pigs in a litter, and they grow very rapidly. A pig doubles its weight in about 14 days from birth, whereas a calf takes 47 days and a child 180 days. As might be expected, the milk of the sow is richer than cow's milk in protein and in mineral salts (see Table 6). The milk of sows, like other milk, is deficient in iron. For instance, Husby [68] found only 0·004 gm. of Fe_2O_3 per 100 c.c. in sow's milk (see also Hart, Elvehjem, Steenbock, Kemmerer, Bohstedt, and Fargo [58]). For this reason sucking pigs tend

to develop anaemia unless their reserves of iron are ample [74]. They can be fed with iron-containing materials [47, 54, 58, 74, 82, 83], but this is somewhat difficult.

TABLE 6. *Analyses of Milk*

	Time taken to double weight after birth	*Weight in grams per 100 ml. of milk*					*Source of figures*
		Protein	*Water*	*Ash*	*Fat*	*Sugar*	
	days						
Man	180	1·6		0·25			Abderhalden and König, quoted by Godden and Husband [41]
Horse	60	2·0		0·38			
Cow	47	3·5		0·72			
Goat	22	4·3		0·81			
Sheep	15	6·5		0·89			
Pig	14	6·7		1·03			
,,		6·2	81·0	1·07	7·1	4·8	Henry & Woll [61]
,,		6·1	80·5	0·98	6·9	5·6	Carlyle[1]
,,		7·9			3·7	4·0	Folin, Denis, and Minot [36]
,,		6·9			6·9	2·0	Pröscher [108]

[1] Quoted by Evvard, Wallace, and Glatfelter [35]

It has been claimed that the composition of the sow's milk can be influenced to a certain extent by alterations in the diet. Thus Thompson [124], by varying the contents of protein and minerals in the sow's diet, obtained milk with as little ash as 0·51–0·86 per cent. It must, however, be emphasized that samples of sow's milk are extremely difficult to obtain [61] and it is doubtful whether the comparatively few samples analysed in the past have been truly representative. Cow's milk, on the other hand, has been the subject of innumerable investigations, and yet no evidence has been obtained that the mineral-content can be altered by changes in the cow's diet. Deficiencies in the cow's diet, however, lead to a decreased yield of milk [5]. This is also true of the sow, as shown by Orr and Davidson [103], who found that a deficiency of lime led to a reduction in the milk supply of the lactating sow. This is a serious matter because the rate of growth during suckling appears to affect the subsequent development of the pig. Thus Thompson [125] showed that pigs which made the most rapid gains during suckling continued to gain most rapidly during the following 60 days. G. N. Murray [99] showed that there was a significant correlation between the weight of pigs at 4 and at 8 weeks, and Wenck [127] showed that pigs which were heaviest at 4 weeks old were also heaviest when slaughtered.

The most critical period in the growth of the young pig is during weaning. Unless this process is carried out gradually and the young pig taught to eat solid food whilst still sucking, growth is always retarded. Hammond [47] considers that retarded growth at this period has an adverse effect on the quantity of muscular tissue laid down by the pig. In particular, he considers that incomplete development of the *longissimus*

dorsi muscle (the 'eye' of meat in the loin) is due to a set-back at weaning (see Plate 9). This is supported by the work of Emmett and Grindley [32], who found that the size of the 'eye' was not affected by the diet after weaning. The 'eye' from the carcasses of pigs on a low-protein diet was just as large as that from pigs on a high-protein ration. It is during weaning that the value of cow's milk and of milk residues is most obvious. Young pigs which obtain a good supply of whole or skimmed milk are less likely to suffer from a set-back at weaning. Cow's milk alone, however, is not capable of supporting growth for prolonged periods. Kemmerer, Elvehjem, Hart, and Fargo [73] have shown that this difficulty can be overcome by adding appropriate quantities of iron, copper, and manganese salts to the milk, together with a supplement of cod-liver oil. Since cow's milk is a potential carrier of bovine tuberculosis to pigs, it should be boiled before use. Unfortunately, boiled milk appears to be less valuable as a foodstuff than unboiled milk [35, 85, 86]. In New Zealand, where bovine tuberculosis is much less common than in this country, the boiling of milk is probably not necessary. It may be pointed out that cow's milk is not the only source of tuberculosis amongst pigs. Fowls infect pigs with avian tuberculosis, and this may account for as many as 30 per cent. of the tubercular lesions observed in pig carcasses in Great Britain [16]. Even with cases of bovine tuberculosis, infection is not necessarily transmitted by milk. Thus in East Anglia, where milk residues are not generally available for feeding to pigs, there are just as many carcasses (about 10 per cent.) showing tubercular lesions as there are in a dairying district like Wiltshire (see Fig. 3).

As soon as it has been weaned, the pig may be fed on a good mixed diet. In order to obtain the maximum increase in weight, the protein-content of the diet should be high at first and can be gradually reduced as the pig grows older. The young pig should have access to grazing or have a sufficient supply of green foodstuff. Dunlop [25] has shown that many diets are dangerously deficient in vitamin A, and that the feeding of green foodstuffs is therefore most important. Hostetler and Foster [67] have shown the great value of permanent pasture for pigs, and Davidson [19] has found that young pigs which are allowed to graze for a few weeks after weaning have an improved constitution and increase in weight more rapidly when fattened indoors afterwards. Mills [91] considered that exercise was almost as important as the feeding of green foodstuffs and that grazing was consequently more beneficial than the feeding of green foodstuffs to pigs kept in sties. Anaemia is more liable to appear in young pigs kept indoors than in those kept outside [23, 43]. A milk supplement has repeatedly been shown to give valuable results [35, 56, 57, 71, 81, 114, 120, 123]. Other animal proteins (meat-meals and fish-meals) give very good results, but vegetable proteins are, on the whole, not quite so satisfactory, even when supplemented with extra salt and lime. A deficiency in the quantity of protein in the diet or the excessive use of an incomplete protein like that of maize retards growth. Deficiencies of accessory food factors or mineral salts also have an adverse effect on growth. Curiously enough, the more rapidly a pig grows, the more likely it is to suffer from a deficiency disease (see Dunlop). Thus

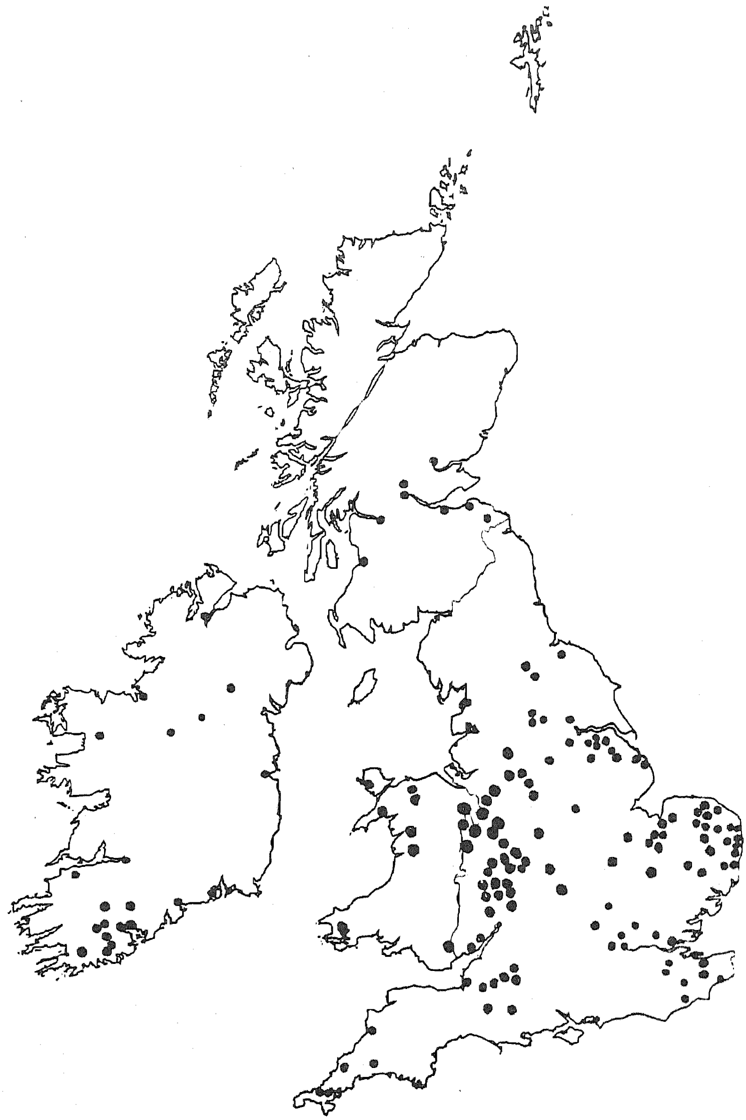

FIG. 3. Centres from which a factory in the Midlands has received pigs with tubercular lesions.

By courtesy of Mr. D. J. Anthony, M.R.C.V.S., D.V.S.M.

Zilva, Golding, Drummond, and Korenchevsky [130] found it necessary to increase the rate of growth of pigs in order to produce rickets. With pigs that were growing more slowly, rickets could not be produced even on diets deficient in the antirachitic vitamin. The deficiency merely resulted in a decreased rate of growth, as compared with control animals on a diet containing an ample supply of the vitamin [42]. Thus an

incomplete diet may be reflected in a slowing down of the rate of growth before more obvious signs of ill health appear.

Davidson [18] has shown that a diet deficient in protein may affect pigs in two ways. If the pig is restless, very thin carcasses are produced, whereas if the pig has a placid temperament, an overfat carcass is produced. The tendency for a low-protein diet to produce over-fatness in pigs was also observed by Shaw [116]. Swanson [123] found that diets deficient in protein or in mineral salts restrict the pig's growth and thus alter the conformation of the resultant carcass. In this connexion it is significant that pigs grown in the maize-belt of the U.S.A. formerly tended to be short and 'chuffy'. Even when the long type of pig was introduced into this area, it reverted to the short 'chuffy' type in a few generations. The reason for this state of affairs was that the diet used for fattening consisted almost exclusively of maize. Maize is deficient in calcium, and its protein, zein, is incomplete as it is deficient in the amino-acid tryptophane. Curiously enough, meat-meal (tankage) is also deficient in tryptophane (see Table 7) and for this reason is not by itself a complete supplement for maize [107]. A tryptophane deficiency can be

TABLE 7. *Amino-acid Content of Some Foodstuffs*

(From Morris, 1934)

Foodstuff	*Tryptophane*[1]	*Arginine*	*Histidine*	*Lysine*	*Cystine*
Dried skim milk	4·54	8·96	6·36	8·34	2·04
Blood-meal	6·51	12·51	5·40	11·04	2·65
Meat-meal	0·63	17·50	3·44	8·80	1·40
Beans (home)	2·29	9·00	4·20	7·45	1·00
Beans (import)	2·33	9·35	4·25	7·44	1·06
Peas	2·56	10·86	3·28	7·04	1·55
Decorticated earth-nut cake	5·20	15·85	9·26	4·46	1·00
Wheat bran	4·30	11·12	4·50	4·40	1·61
Linseed cake	2·87	15·18	5·69	4·21	1·14
Linseed	2·80	15·76	5·75	3·34	1·00
Oats	3·99	11·66	5·90	2·98	0·69
Flaked maize	1·78	8·29	2·36	2·15	1·48
Beet-pulp	3·10	0·56	0·49	0·23	0·32

[1] Tryptophane was estimated approximately as insoluble humin. The figures for amino-acids are expressed as grams of amino-nitrogen per 100 grams of total nitrogen.

overcome by feeding alfalfa, and in the maize-belt nowadays a longer and leaner type of pig is being produced by using a diet of maize, meat-meal, and alfalfa. Hogan [65] has pointed out that, under rigidly controlled experimental conditions, most of the diets in ordinary use turn out to be highly unsatisfactory. He searched for possible deficiencies but could not solve the problem. The unsatisfactory condition of the pigs could not be traced to an unsuitable Ca to P ratio, nor to deficiencies of vitamin C or sunlight, nor to lack of exercise. More recently, however, Dunlop [25] has shown that normal diets are dangerously short of vitamin A, and that consequently the feeding of a supplement containing

this vitamin or its precursor, carotene, is of great importance. Other vitamin deficiencies appear to be rare in pigs and only occur with abnormal diets. Thus Plimmer [105] recorded a case of scurvy in pigs fed on an exclusive ration of cooked food. With the increase of intensive pig-production, however, it is possible that diseases due to deficiencies in diet may become more acute and that sources of deficiency, hitherto unsuspected, may be revealed in the future.

Just as an incomplete diet has a retarding effect on growth, a high-grade diet has a stimulating effect. It is impossible to estimate the maximum capacity for growth of pigs of any breed or strain unless an optimum diet is used. Thus, Clausen [15] states that every pig has an individual capacity for flesh-formation which cannot be gauged unless the rations contain sufficient proteins and other foodstuffs to permit the optimum growth. In this connexion the outstanding merit of carcasses of frozen pork from New Zealand deserves mention. The proportion of flesh on these carcasses is usually greater than that of our English porkers and baconers (see Plate 8). There is little doubt that this result, obtained even with such a short fat breed as the Berkshire, shows the advantages obtained from an ample supply of milk and milk-residues, together with open-air management and grazing. It is also possible that the excellent quality of the carcasses from New Zealand is in part due to the wide-spread use of *unboiled* milk and milk residues for feeding [35, 85, 86]. It is significant that defects in the *longissimus dorsi* muscles ('eye' of loin) are seldom or never seen in these carcasses.

Composition of deposited fat.—The effect of alterations in the diet on the chemical composition of the tissues is most marked in the case of fat. The chemical nature of the fats and oils in the diet may have a considerable effect on the composition of the fat deposited in the tissues. If the diet is practically free from fat, the pig synthesizes fat from carbohydrate and indirectly from proteins. Fat produced in this way is relatively saturated and has an iodine number of 50 to 60 [30]. This type of fat is solid at ordinary temperatures and thus gives firm carcasses. When fats and oils are present in the diet, the fat laid down in the tissues tends to resemble the ingested fat. If there is only a small amount of fat in the diet, most of the fat deposited in the animal will come from carbohydrates, and the influence of the ingested fat will be slight. As the amount of fat and oil in the diet increases, however, less and less fat is synthesized from carbohydrate and more of the deposited fat is formed from the fat in the food. The effect of the ingested fat on the chemical composition of the deposited fat is more marked in immature pigs [49]. In the young pig the rate of fat-deposition is slower than it is in older pigs. When immature, the pig can thus obtain a greater proportion of the fat that it requires for deposition from the fat and oil in its diet, but as the rate of fat-deposition increases, more and more fat has to be synthesized from carbohydrate. Since most of the fats in the pig's diet are highly unsaturated (see Table 8), the deposited fat of young pigs tends to be more unsaturated, and hence softer, than that of older pigs [26, 49, 75] (see Fig. 2).

The rate of growth also has an effect on the nature of the fat deposited

TABLE 8. *The Fat-content of Various Foodstuffs and the Iodine Number of the Extracted Fat*

	Fat-content	*Iodine number*	
	Per cent.		
Barley meal	1·6	124·6	Callow and Kitchin (unpublished results)
" "	1·6	116·7	
Oats (crushed)	3·3	100·5	
Wheat middlings	4·3	128·4	
" "	3·9	126·7	
Fish-meal	2·2	151·1	
"	2·2	169·9	
Bran	3·3	127·6	
Extracted soya-bean meal	0·5	134·8	
Sago-pith meal	0·2	75·3	
Wheat middlings	4·2	115·4	Lewkowitsch and Warburton [80]
Maize	4·3	126·0	Hankins and Ellis [49]
Acorns	4·4	100·7	
Rice polish	9·7	100·0	
Rice bran	14·8	100·0	
Chufas (dry)	28·9	76·5	
Whole peanuts	33·1	93·7	
Shelled peanuts	47·6	93·7	
Soya-bean-oil meal	6·6	128·0	
Cotton-seed meal	6·8	107·4	
Peanut meal	9·0	93·7	
Tankage	10·9	64·5	
Fish-meal (menhaden)	11·0	124·8	
Soya-bean meal	17·5	128·0	
Linseed oil		177·2	Henriques and Hansen [59]
Coconut oil		8·1	
Whale oil		110·1 to 136·0	Lewkowitsch and Warburton [80]
Cod-liver oil		153·7 to 167·3	
Menhaden oil		139·2 to 192·9	

by the pig. A pig which grows slowly usually has a lower rate of fat-deposition and therefore does not need to synthesize fat from carbohydrate to the same extent as a rapidly growing pig with a higher rate of fat-deposition. The fat produced by the slowly growing pig is therefore more likely to resemble the ingested fat and to be relatively unsaturated and soft. This was recognized by Day [21] who stated that in his experience 'unthrifty hogs are more likely to produce soft bacon than growthy, well-fed hogs'. Evidence of this has also been obtained by Callow and Kitchin [12] who found that, on the average, the subcutaneous fat from slowly growing pigs was more unsaturated than the fat from rapidly growing ones (see Table 13). Ellis and Zeller [31] have also shown that slow growth tends to produce leaner pigs with a more unsaturated fat, than does more rapid growth. It is significant that the fat of wild boars (iodine number = 81·5 to 84·7, Lewkowitsch and Warburton [80]) and of pigs in a semi-wild condition where growth is

restricted (iodine number = 79·0 to 95·2) is more highly unsaturated than normal fat [111, 112].

At all stages in the development of the pig, alterations in the quality or quantity of the fat in the diet lead to variations in the chemical composition of the deposited fat. As already mentioned, nearly all the foodstuffs commonly fed to the pig contain highly unsaturated oils with relatively high iodine numbers (see Table 8). On normal diets, therefore, the deposited fat of the pig tends to be more unsaturated than it is on a fat-free diet. Conversely, it is possible to reduce the iodine number of the pig's fat by feeding foodstuffs that contain relatively saturated fats. This was clearly shown by Henriques and Hansen [59] in their classical researches on the effect of ingested fat on the body fat of the pig. These workers fed pigs on a diet containing a high concentration of coconut oil (iodine number 8·1) and removed samples of subcutaneous fat from the living animal for analysis. The results showed that the iodine number of the pig's fat was decreased by feeding the highly saturated coconut oil (see Table 9). Gibbs and Agcaoili [40] in the Philippine Islands obtained

TABLE 9. *The Effect of Feeding Coconut Oil and Linseed Oil*

(From Henriques and Hansen, 1899)

Pig	*Period*	*Food in gm. per day*		*Iodine number of back fat*
		Oil	*Barley*	
1	Oct. 1–15	125 c	725	70·3
	Oct. 16–Nov. 15	200 c	1,225	57·5
	Nov. 16–Dec. 9	250 l	1,725	71·8
	Dec. 10–Feb. 2	300 l	2,000	92·8
	Feb. 3–Mar. 17	400 l	2,225	100·3
2	Oct. 1–15	125 l	1,000	70·9
	Oct. 16–Nov. 15	200 l	1,500	109·2
	Nov. 16–Dec. 9	250 c	2,000	88·3
	Dec. 10–Feb. 2	300 c	2,225	83·8
	Feb. 3–Mar. 17	400 c	2,500	69·7

c = coconut oil with an iodine number of 8·1.
l = linseed oil with an iodine number of 177·2.

pig-fat with the very low iodine number of 30 from a pig which had been fed mainly on coconuts. The effect of feeding a diet containing large quantities of a highly unsaturated oil (linseed oil with an iodine number of 177·2) was also investigated by Henriques and Hansen [59], who showed that the resultant body fat of the pig became highly unsaturated (see Table 9). These workers also showed that the caul fat of the pig was the most saturated fat in the body, the kidney fat was less saturated, and the outer layer of subcutaneous fat was the most unsaturated of any deposited fat (see Table 10). There is thus a gradient in the degree of unsaturation of the fat from the inside to the outside. Henriques and Hansen [60] considered that this was due to the gradient of temperature in the body, and that the higher the temperature at which fat is laid down, the more saturated it is. In further support of this theory they

TABLE 10. *Gradient in the Degree of Saturation of the Fat of the Pig*

(From Henriques and Hansen, 1901)

Foodstuff	*Location of fat*	*Iodine number*	*Setting-point*
Barley	Outer layer of outer back fat	60·0	..
	Inner layer of outer back fat	57·1	26·4° C.
	Outer layer of inner back fat	51·8	28·0° C.
	Inner layer of inner back fat	50·6	27·7° C.
	Kidney fat	47·7	29·6° C.
	Caul fat	46·5	29·4° C.
Maize	Outer layer of outer back fat	72·3	22·8° C.
	Inner layer of outer back fat	70·5	24·1° C.
	Outer layer of inner back fat	65·5	25·7° C.
	Inner layer of inner back fat	64·2	25·6° C.
	Kidney fat	56·6	28·4° C.
	Caul fat	56·1	29·1° C.

showed that the degree of saturation of the fat could be varied by altering the temperature of the pig's living quarters (see Table 11). A pig kept for 2 months at 0° C. had a more unsaturated fat than one kept at 30° to 35° C., or one kept at 0° C. but covered with a sheep-skin. Similarly Friis [39] found that the feeding of maize produced softer (and hence more unsaturated) fat in cold weather than in hot weather. It seems

TABLE 11. *Effect of External Temperatures on the Fat of the Pig*

(From Henriques and Hansen, 1901)

Temperature of living quarters	*Outer layer of outer back fat*	*Inner layer of outer back fat*	*Outer layer of inner back fat*	*Inner layer of inner back fat*	*Kidney fat*	*Caul fat*
	Iodine number	Iodine number	Iodine number	Iodine number	Iodine number	Iodine number
30°–35° C.	69·4	66·2	62·5	61·5	58·1	54·7
0° C.	72·3	70·5	65·5	64·2	56·6	56·1
0° C. but pig wrapped in sheep-skin	67·0	65·2	62·4	62·3	53·8	51·2
The same pig before experiment	69·4	67·3	63·3	62·9		

possible, however, that this effect of low temperatures may be due, at least in part, to the slowing down of growth, which would be expected in these circumstances.

Henriques and Hansen [60] showed that the feeding of maize to pigs produced a more unsaturated fat than the feeding of barley (see Table 10). Other workers have shown that the actual chemical structure of the pig's fat is affected by the fat in the diet (e.g. Ellis and Isbell [27]). Thus Martin [87] found a small proportion of the glyceride of clupanodonic acid in the fat of pigs which had received fish-meal in their diet. By feeding menhaden oil, Brown [7] obtained direct evidence that the fat

from the diet could afterwards be detected in the fat of the pig. Bhattacharya and Hilditch [6] have shown that the feeding of arachis oil definitely leads to an increase of linoleic acid in the deposited fat.

During starvation, or growth on maintenance diets, the body fat of the growing pig is utilized and therefore gradually diminishes in quantity. It is probable that the more unsaturated fats are utilized first. There is direct evidence that this occurs with rabbits [22], and Anderson and Mendel [1] have obtained indirect evidence with rats. Like other workers, Anderson and Mendel found that diets containing highly unsaturated oils lead to the deposition of highly unsaturated body fats. They also showed that the unsaturated body fat of the rat could be made more saturated by feeding a diet containing a more saturated fat, and that this change was accelerated by a previous period of starvation. In the case of the pig, it should be pointed out that, although the unsaturated soft fat deposited by feeding a diet containing too high a proportion of highly unsaturated oils can be altered considerably by substituting a relatively fat-free diet, or one containing more saturated (harder) fats, it is exceedingly difficult to remove all traces of the unsaturated fats deposited from the original diet [27, 49, 70, 71].

The effect of various diets on the quality of the deposited fat has been investigated on a large scale in the U.S.A. within recent years [26, 27, 28, 29, 30, 49, 50]. These researches have established a relationship between the degree of hardness of the deposited fat of the pig and the iodine number and refractive index of the fat (see Table 12). Ellis and his co-workers showed that on normal diets the fat of the pig becomes progressively harder with age [26, 49] (see Fig. 2). However, with diets containing a large quantity of an unsaturated fat like peanut-oil (iodine

TABLE 12. *Average Iodine Number, Refractive Index, and Melting-point of Pig Fats*

(From Hankins and Ellis, 1926)

Type of fat	*Iodine number*	*Refractive index*	*Melting-point*
Hard	63·0	1·4593	38·0° C.
Medium hard	68·0	1·4599	36·5° C.
Medium soft	71·0	1·4603	35·0° C.
Soft	77·5	1·4611	31·0° C.
Oily	88·0	1·4623	24·0° C.

number 93·7), the deposited fat may actually become more unsaturated and softer as the pig develops. The subsequent feeding of a normal diet leads to a progressive hardening of the fat as the pig becomes older, but the fat never becomes as hard as that from pigs which have received a normal diet throughout the whole experimental period [27, 49]. The effect of diet on the resultant fat has been investigated in many countries and the same general results have been obtained [12, 21, 39, 40, 59, 60, 70, 98, 100, 104, 106, 118, 119]. Jackson [70] has pointed out that when highly unsaturated fats are present in the diet it is advisable to keep the total quantity of fat in the diet lower than usual.

Muscular tissue and bone.—Although diet has a marked effect on the

nature of the deposited fat in the pig, it has relatively little influence on the chemical composition of bone and muscle. An insufficient supply of calcium and phosphorus, however, is reflected in an impaired growth of bone, and consequently cereals alone will not produce a normal growth of bone [38]. Even when the supply of calcium and phosphorus was constant, Maynard and Miller [90] found that the degree of calcification varied with different protein supplements. Better calcification was obtained with a ration containing fish-meal or blood-meal and casein than with one containing linseed-oil meal. Sunlight helps to form vitamin D in the body and is therefore most important in bone-formation [89]. It can, however, be replaced by cod-liver oil and other foods that are rich in vitamin D. An adequate growth of bone is highly important as it increases the size of individual bones, and there is some evidence that the degree of development of an individual bone affects the size of the attached muscles, a more highly developed bone having larger muscles attached to it [48].

Curiously enough, although muscular tissue is the most valuable part of the carcass, there is very little evidence about the effect of diet on its composition. With increasing age, muscles contain less water and more fat. It has been suggested that water and fat are complementary [2] and that a change such as starvation which leads to depletion of fat also leads to an increase in the water-content of the muscles [94]. The converse is certainly approximately true, as an increase of fat in the muscle is accompanied by a decrease in the water (see Table 4). The concentration of inorganic matter (ash) in the muscular tissues of the pig can be altered to some extent by altering the diet [37]. The chemical nature of the muscular proteins, however, does not appear to be affected by diet. Thus, when the supply of protein in the pig's diet was deficient either quantitatively or qualitatively, Joseph [72] found no alteration in the composition of the proteins of the muscles. It is generally supposed that the amount of connective tissue in most animals is increased by exercise, but pigs seldom get violent exercise and this factor is probably unimportant. Cuts of pork from different parts of the same carcass show only slight variations in the amount of connective tissue and consequent toughness [93]. In the case of bacon, however, shoulder cuts tend to be tougher and coarser than the rest of the carcass.

Quality of carcass.—The quality of a pig's carcass can only be considered in relation to the particular purpose for which it is intended. Thus the type of carcass which is most suitable for the manufacture of bacon is quite different from that required for small pork. With both pork and bacon, however, the consumer shows a preference for cuts with a large proportion of lean meat which is almost completely separated from the fat [46]. These cuts command the highest prices and come from the loin and hind quarters of the carcass. As Plate 10 shows, the prices for joints and cuts increase along a fairly well-defined gradient from head to tail, and it is significant that the most valuable parts of the carcass are those which develop late in life [46]. The ideal carcass for both pork and bacon is therefore one with a long body, well-developed hams, well-sprung ribs, and a small head and shoulders [46].

Although the relative conformation of carcasses should be approximately the same for both pork and bacon [46], the weight should vary according to the purpose for which the carcass is required. Thus, for small joints of pork, the carcass should weigh only 60 to 80 lb. dead-weight. This class of carcass is in great demand in London and in the south of England, and is becoming increasingly popular all over the country [110]. There is also a market for carcasses of 80 to 100 lb. dead-weight for medium-sized joints of pork. In the Midlands and in the north of England, where larger joints are still in demand, carcasses are required which weigh from 100 to 140 lb. dead-weight. With these heavier carcasses it is customary, in some parts of the country, to remove a large proportion of the back fat before cutting up into retail joints. Still heavier carcasses are required for bacon. For Wiltshire curing, the carcasses should weigh between 140 and 170 lb. dead-weight. In Great Britain, increasing numbers of pigs of this class are needed because an attempt is being made to increase our supplies of home-produced Wiltshire sides of bacon. The Midland curer has more flexible methods than the Wiltshire curer and consequently can handle carcasses between 130 and 210 lb. dead-weight. In the Wiltshire cure, whole sides are converted into bacon, but in the Midland cure the sides are cut up before curing. All superfluous back fat is trimmed off, and the hams are removed and cured separately, usually as York hams. The rest of the sides are either cured as Midland 'specials', or the loin is cut off for use as pork and the remainder cured as a 'shoulder belly'. In summer months pickled pork may be made from the lighter carcasses instead of bacon and hams.

In order to obtain these widely different carcass weights, and yet to keep as near as possible to the ideal conformation, different breeds and strains may be used. Early maturing breeds, such as the Middle White or Berkshire, are more suitable for small pork, whilst late-maturing breeds like the Large White are more suitable for bacon. The early-maturing pig which is most suitable for small pork is definitely unsuitable for bacon. On the other hand, Davidson [17] has shown that it is possible to use a late-maturing breed (the Large White) for the production of small pork carcasses.

For whatever purpose it is intended, the carcass should not only possess the correct conformation but should be well 'finished', i.e. the fat should be hard, and sufficient fat should have been laid down in the muscles, especially those of the abdominal walls (the flank), to give a firm carcass when cool. Unless this is the case, the lean meat will tend to dry out after cooking. There should be a relatively high proportion of lean meat, and it should be tender, have a full flavour, and be not unduly pale in colour. There is also a demand for fine, thin, white skins, as these possess a 'bloom' which attracts the buyer. Breeds which are pigmented and which are therefore liable to have pigmented mammary glands, 'seedy-cut' [84], are in great disfavour with butchers and curers, as the unsightly appearance necessitates the cutting away of the mammary tissues.

The most common defects in quality met with in pork and bacon are over-fatness, soft fat, insufficient development of muscular tissues (see

Plate 9), and bad 'finish'. Occasionally, bacon is too pale in colour. Over-fatness is a very common fault in bacon pigs, and pig producers in this country are now penalized for sending over-fat carcasses to the bacon factory. Over-fatness is caused by allowing the animal to grow beyond the desired point. Bad 'finish' is usually due to the exactly opposite fault of killing the animal before it has reached its optimum degree of fatness. Insufficient development of the muscular tissue appears to be due to incorrect feeding during weaning [47], and possibly to a deficiency of high-grade protein in the diet either during weaning or afterwards. An unduly pale flesh may be due to anaemia or to lack of exercise. The more a muscle is used the greater is its content of haemoglobin [101] and hence the deeper is its colour. Curiously enough, there is as yet no evidence that exercise can increase the quantity of muscular tissue [46]. The composition of the muscular tissue appears to depend upon the rate of growth [11]. Hansson [52] found that pigs which grow most quickly produce a better quality of carcass than slowly-growing pigs. In the results obtained for the East Anglian Pig-Recording Scheme [20], however, the highest quality pigs had an average growth-rate below that of pigs in lower grades, but this was due, at least in part, to the fact that the more rapidly growing pigs were grown to heavier weights and therefore had thicker back fat than the slowly growing pigs. This affected the grading because a thin back fat is preferred to a thick one. Similarly, gilts, which grow more slowly than hogs [99], tend to give better bacon carcasses because the back fat is thinner [20]. Another point in favour of gilts is that extra growth of the mammary tissues increases the thickness of the flank.

Quality of fat.—Soft fat is due to immaturity [27, 49] or to incorrect feeding [49, 50, 55, 70]. Soft fat is unpopular because it tends to give unsightly carcasses and causes extra losses during cooking. Moreover, soft fat is more liable to develop rancidity because it is more unsaturated than hard fat, and is therefore more reactive chemically. Unsaturated fats tend to take up oxygen from the atmosphere and form peroxides, which in their turn undergo further chemical changes. Finally aldehydes and ketones are produced, and these are responsible for the acrid flavour that is associated with rancidity. In cases of extreme rancidity, a yellow colour may appear in the fat [8]. Unfortunately, the changes leading to rancidity are catalysed by light [77] and by the salts used in curing [79]. It is therefore not surprising that bacon fat is more liable to develop rancidity than pork fat [9]. Since the oxidation of fat is autocatalytic in character [77], the onset of rancidity may be quite sudden. The time factor is thus of great importance. Bacon which undergoes a long period of manufacture, such as Midland-cured bacon (3 to 5 weeks), is more liable to become rancid than Wiltshire bacon which is produced more rapidly (2 to 4 weeks). The still greater length of time taken to manufacture York hams (3 to 6 months) renders them particularly susceptible to rancidity. The fat of carcasses intended for the manufacture of York hams must therefore be of excellent quality, because soft fat, which might be undetected in pork or Wiltshire bacon, will lead to noticeable rancidity before the slowly maturing York ham is ready for the market.

Rancidity, however, is not merely a question of the softness of the fat or its degree of unsaturation, as measured by its iodine number. Although fats with high iodine numbers nearly always develop rancidity more rapidly than fats with lower iodine numbers, there are certain cases in which the reverse is true. These curious cases occur when small quantities of highly unsaturated oils, such as cod-liver oil, are present in the diet. Small daily doses of cod-liver oil have little or no effect on the iodine number of the deposited fat of the pig, but the cod-liver oil increases the chemical reactivity of the deposited fat and makes it more liable to develop rancidity. Thus, in an experiment carried out by Callow and Kitchin [12], the deposited fat of the pigs which had received a small daily dose of cod-liver oil in their diet had a lower average iodine number than that from pigs on a low-protein diet, and yet bacon made from the cod-liver oil group had fat which developed rancidity more rapidly (see Tables 13 and 14).

TABLE 13. *Growth-rate and Iodine Number of Fat*

(From Callow and Kitchin, 1931)

Diet	*Average growth-rate lb./days*	*Average iodine number of back fat*	
		Inner fat	*Outer fat*
Basal ration	1·71	58·5	62·0
Basal ration plus malt extract and cod-liver oil	1·67	59·9	62·5
Basal ration plus malt extract . . .	1·63	59·4	62·0
Limited feeding with basal ration . .	1·44	61·9	64·8
Low protein ration	1·24	62·1	64·6

TABLE 14. *Development of Rancidity during the Cold Storage of Bacon made from Pigs in Table 13*

(From Lea, 1931 [78])

Diet	*Measurement of active oxygen of back fat of bacon stored at −10° C. (14° F.) for 85 days*
Basal ration	2·2 ml.
Low protein ration	1·7 ml.
Basal ration plus malt extract and cod-liver oil	12·75 ml.

The active oxygen was measured at a distance of one inch from the exposed surface of the back fat and is expressed as ml. of *N*/500 thiosulphate. Results below 4 ml. indicate that the fat is free from rancidity. A figure of 10 ml. or more indicates a highly rancid fat.

Undoubtedly cod-liver oil is a good source of vitamins A and D, but its value as a supplement to the diet of the pig is complicated by the fact that it is a highly reactive oil which may have a deleterious effect on the deposited fat [104]. Since halibut-liver oil contains far more vitamin A

and D than cod-liver oil, a much smaller dose is required, and the effect of the actual oil on the deposited fat should be almost negligible. From this point of view the ideal source of vitamin D would be irradiated ergosterol. The addition of cod-liver oil to the diet undoubtedly produces pigs with a good appearance which yield carcasses with reasonably hard fat. It is impossible for the bacon curer to detect any abnormality in the fat of such carcasses while they are being cured, and yet rancidity may suddenly develop later. By this time the carcasses will have been manufactured into bacon and hams, and these may even be in the retailers' hands. A case in point occurred in Great Britain in 1933. Ninety-seven pigs, which had received a daily dose of cod-liver oil, were sent to a Midland curer. The carcasses looked exceptionally good, but the resultant bacon and hams rapidly developed rancidity. In every case the fat became yellow, and the bacon and hams were completely unsaleable. The outer layer of back fat from one of these carcasses was found to be not unduly soft and had an iodine number of 68·6, which is not abnormally high. Here, as in the experiment of Callow and Kitchin (see Table 13), the cod-liver oil supplement had not seriously affected the iodine number but had greatly increased the reactivity of the fat.

The rapid onset of rancidity which frequently follows the use of cod-liver oil in the diet is probably due to the presence of certain highly reactive linkages that are found in liver oils. A small quantity of oil, containing these linkages, in the diet would not have much effect on the average iodine number of the deposited fat, but it would probably have an accelerating effect on the subsequent rate of development of rancidity. A highly unsaturated oil is also found in fish-meal (see Table 8) and, in the past, rancidity of bacon fat has often been traced to the presence of fish-meal in the diet [70, 102, 109]. These cases were mainly due to the use of fish-meal containing too high a proportion of oil, or to the use of excessive quantities of fish-meal in the diet. It appears that pigs can be reared satisfactorily by using white fish-meals containing less than 5 per cent. of oil and discontinuing its use for a month before slaughter [129]. Even this amount of fish oil, however, might have a deleterious effect if the carcasses had to be kept for prolonged periods as in the Midland cure or in the manufacture of York hams.

A high quality of fat is obviously necessary for carcasses of pork which are intended for freezing and storage. This is particularly the case with imported frozen carcasses which are intended for the manufacture of bacon in Great Britain. Normally the frozen carcasses that arrive from Australia and New Zealand have fat of very high quality, but in 1929 there were a large number of cases of yellow rancid fat in bacon made from frozen carcasses from New Zealand. One sample of this fat had an iodine number of 81, and was therefore very soft. The cause of this abnormally soft unsaturated fat was traced to the use of whale oil in the diet, and this was immediately discontinued.

It has already been shown that the quality of pig carcasses depends upon the purpose for which they are intended. Thus, in the maize-belt of the U.S.A., when pigs were grown for lard, a short, 'chuffy', over-fat type of pig was encouraged. The pig was grown to 250–300 lb. in

weight and fattened beyond the point usual in Great Britain. In this way a fairly hard fat was obtained, in spite of the softening nature of maize-oil. Nowadays, however, the demand for genuine lard is diminishing owing to the increase of substitutes produced by the hydrogenation of vegetable oils [113, 126]. For this reason, together with the increasing demand for leaner joints and cuts, the short 'chuffy' type of pig in the maize-belt is rapidly being supplanted by a longer and leaner animal.

Carcass quality and bacon-curing.—The quality of carcasses used by the bacon curer has a far-reaching effect on the quality of the resultant bacon. 'Unfinished' carcasses are more difficult to cure satisfactorily, because the very lean meat of 'unfinished' sides takes up salt too rapidly and thus tends to become over-salt [4]. Moreover, during dry-salting and smoking, lean 'unfinished' sides lose more weight than sides from more mature and fatter pigs [10]. Bacon made from more mature pigs also has a fuller flavour.

Measurement of carcass quality.—In the past, measurements of quality have been chiefly concerned with carcass-conformation and with the hardness of the fat. A considerable amount of valuable work has been carried out on the chemical composition of fatty tissues, but owing to its complicated nature, the chemical composition of muscular tissue is still far from being understood. Little is known of the exact distribution of fat in the muscular tissues. Hankins and Ellis [51] have shown that the general state of fatness of the pig can be estimated by measuring the average thickness of the back fat. Callow and Davidson [11], however, found little or no correlation between the thickness of the back fat and the amount of fat in a single muscle (the *psoas* muscle). In this work the fat- and water-contents of the muscular tissue were determined by laborious chemical analyses. It would undoubtedly be of great practical value if the degree of fatness of lean meat could be estimated by some simple physical method which could be carried out on an intact carcass. It is probable that the electric probe method of Banfield [3] could be adapted for this purpose. This method was originally devised to determine the salt concentration of bacon by measuring its electrical resistance. Banfield and Callow have now tested fresh meat with the electric probe and have shown that the presence of fat increases the electrical resistance of muscular tissue. Thus, minced meat containing 0·9 per cent. of fat had an electrical resistance of 266 ohms, whereas with minced meat containing 3·3 per cent. of fat the electrical resistance was 280 ohms. Moreover, an exceedingly lean, intact side had a much lower resistance at all points investigated than an exceedingly fat side (see Table 15).

Banfield and Callow have also found that the electrical resistance of the muscular tissues decreases from head to tail, being greatest at the shoulder and least in the gammon (see Table 15). This suggests that there is a gradient of fat-content in the muscular tissues from head to tail, most fat being found in the muscles of the shoulder and least in the gammon.

Quality and future research.—Further research still remains to be done on the effect of diet and management on quality. For example, we do not yet fully understand the causes of badly developed muscular tissue. Occasionally this defect is so marked that more than half the muscular

TABLE 15. *The Electrical Resistance of Muscular Tissues at Various Points in the Carcass*

(Banfield and Callow; unpublished results)

	Shoulder	*Middle of back*	*Loin*	*Gammon*
	ohms	ohms	ohms	ohms
Excessively lean side	680	520	560	420
Excessively fat side	1,430	1,380	1,380	1,060
Average of eight sides	989	993	878	663

tissue of a particular muscle is replaced by fat (see Plate 9), and replacement by fat to the extent of 10 to 20 per cent. is not uncommon. Little is known about the relative rates of deposition of fat in various parts of the pig's body, or about the utilization of the reserves of fat during starvation or on maintenance-diets. We also need information about the individual growth-rates of bone, connective tissue, muscle, and fat; and the relation between these growth-rates and the conformation and quality of the resultant carcass is of fundamental importance. Other questions that arise are the effect of the quality of the carcass on the actual processes involved in curing and on the quality of the final bacon. Above all, quality should be correlated with all the factors involved in the chain of production, which extends from the breeding herd to the resultant pork or bacon.

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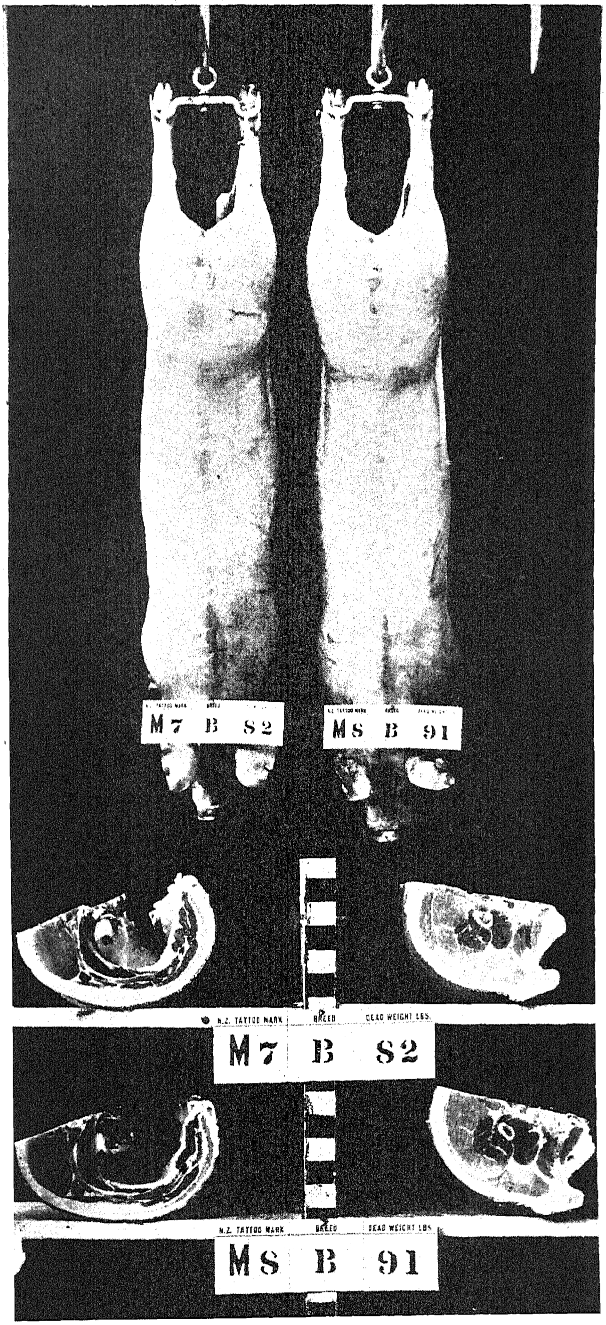
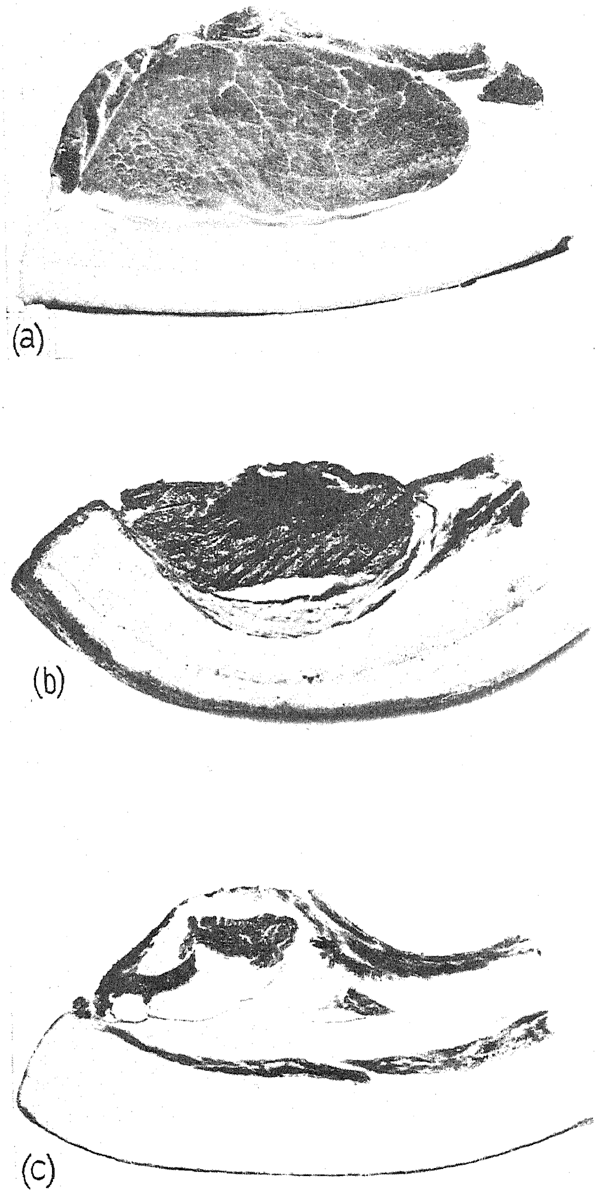


CARCASSES OF VERY LEAN BERKSHIRE PIGS FROM NEW ZEALAND

The frozen carcasses were cut up at Smithfield, and two cuts from each are shown. The 'eye' of the loin is remarkably well

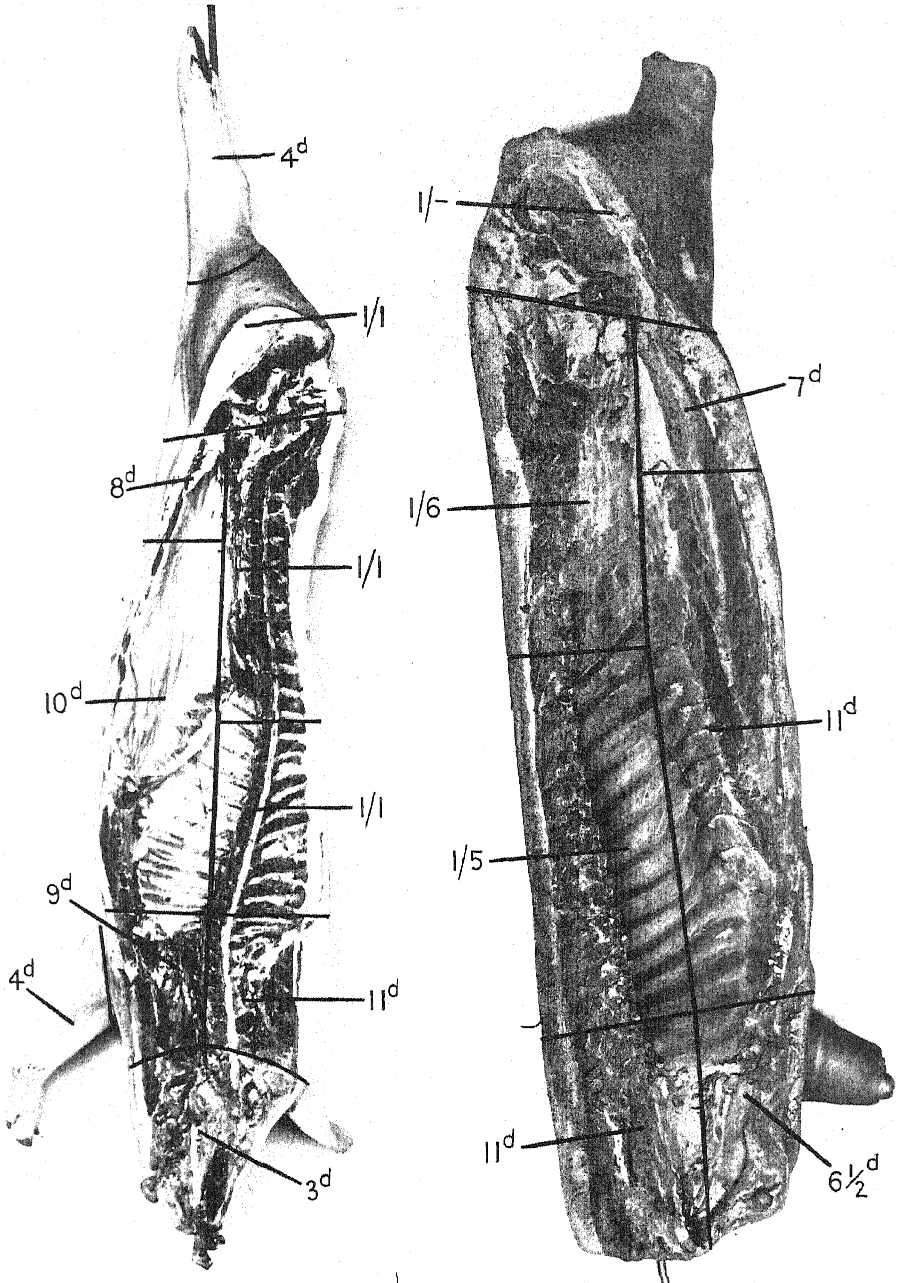


VARIATIONS IN 'EYE' OF BACON

(*a*) Fairly good, and above the average

(*b*) Definitely bad, but not far below the average

(*c*) Unusually bad. This side of bacon, however, did not appear to be abnormal until it was cut up



A SIDE OF PORK AND A SMOKED SIDE OF BACON SHOWING POSITION OF CUTS AND THE RETAIL PRICES FOR OCTOBER, 1934

The sides belonged to F. Winton Smith, Ltd., of Cambridge, who kindly supplied the information about the cuts and prices. (There may be local variations in the method of cutting up sides, and variations in the market prices may lead to alterations in the relative proportions of the different cuts)

I. A. R. I. INST. AGR.

STUDIES IN THE YIELD OF TEA

Pt. III. FIELD EXPERIMENTS WITH POTASH AND NITROGEN IN RELATION TO THE PRUNING CYCLE[1]

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The nutritional requirements of tea from the standpoint of soils and fertilizers have recently been summarized by Mann [1] and the writer [2] in this *Journal*. The present account deals in some detail with experiments in Ceylon covering a complete pruning cycle, i.e. the growth-period between successive pruning operations, which is the natural agricultural and physiological time unit on which to base experimental work with this crop.

At the time of its inception the experiment had to be designed without the detailed knowledge of orthogonal arrangements which Yates [3] has since provided, and for this reason, with the land available, a definite limit was set on the number of different nutrients that could be included. Consequently the questions asked were reduced to three, which at that time were of paramount agricultural importance. These, and the reasons for their selection, were described in the previous paper (loc. cit.), but for convenience may be restated here.

(1) *The relationship between quantity of nitrogen and yield.*—Agricultural practice in Ceylon in 1930 was as a whole tending to adopt increasing doses of nitrogenous manures, but no exact knowledge of the nature of the crop response was available.

(2) *The value of organic and inorganic sources of nitrogen.*—Tradition and circumstance dictated that a considerable portion, if not all, of the nitrogen should be in 'organic' form, i.e. the residues of oil-bearing seeds or animal offals; and it was contended that the sole use of inorganic nitrogen led to uneven cropping and deteriorated quality in the finished product.

(3) *The effect of potash on crop response.*—This was regarded by many as negligible, but the view was nevertheless seldom carried to the logical conclusion of omitting this nutrient altogether.

The experimental scheme thus embraced three variables, two relating to quantity, and one to the quality of the nutrients applied, and its design was such that, as time and experience with a new technique of experimentation progressed, other variables could be included. Subsequent to Yates's paper (loc. cit.), variable phosphatic dressings have been included.

Experimental Design

The details of experimental design and management were based on the technical study of experimental error which formed the first paper of this series [4].

[1] Parts I and II of this series, dealing with the technique of tea experiments, appeared in the *Journal of Agricultural Science*, 1931, **21**, 547, and 1932, **22**, 386, respectively.

The general manurial scheme was as follows:

$$\begin{array}{lll} N_0\ K_0\ P_{30} & N_0\ K_{20}\ P_{30} & N_0\ K_{40}\ P_{30} \\ N_{20}\ K_0\ P_{30} & N_{20}\ K_{20}\ P_{30} & N_{20}\ K_{40}\ P_{30} \\ N_{40}\ K_0\ P_{30} & N_{40}\ K_{20}\ P_{30} & N_{40}\ K_{40}\ P_{30} \end{array}$$

The numerical suffixes indicate pounds per acre of nitrogen, potash, and phosphoric acid. Potash was supplied as muriate, and phosphoric acid as superphosphate. The nitrogen was given in three forms, blood-meal, cyanamide, and sulphate of ammonia, and these direct treatment effects were orthogonal with nitrogen and potash quantity and their interactions. Information on the interactions between quality of nitrogen and potash quantity was not available without fitting constants, owing to confounding with blocks.

Other experimental details were:

Size of plot: 1/12th acre (approximately 250 bushes).
Replication: sixfold in randomized blocks of nine plots.
Time between individual pluckings: 9 days.
Number of plucking rounds: 1st year, 25
2nd ,, 41
3rd ,, 40
Length of cycle: 3 years. Initial date: November 1930.
Cultivation: forking annually at time of manuring.
Yields: dry weight on basis of replicated samples from each plot.

The plot was made slightly larger than the optimum in order to provide sufficient leaf for subsequent experimental manufacture of the produce (see Appendix). The degree of replication, based on previous study, was deemed to be capable of giving a standard of significance that would fall within the limits of agricultural importance. This was borne out by the results obtained; the standard errors of means for the experiment in parts and as a whole are given in Table 1.

'Tippings' are those shoots which develop after pruning and are broken back before plucking proper begins.

TABLE 1. *Accuracy of Experimentation: Standard Error of Mean (per cent.)*

	Tippings	*1st year*	*2nd year*	*3rd year*	*Total yield*
For nitrogen and potash quantities . .	2·57	1·91	1·79	2·52	1·86
For types of nitrogen .	3·14	2·34	2·18	3·09	2·27

The second year gave the most satisfactory results. It owes its superiority over the first year in all probability to the greater number of harvests, and to the fact that by that time a high degree of uniformity in the plucking surface was attained. By comparison, the third year shows the defects which a cumulative individuality in bush development can produce.

Plucking Yields

In Table 2 the yields from the various main treatments are set out for the constituent periods of the experiment; the significance of the manurial effects is judged from the analyses of variance in Table 3. Where the general treatments have been effective the appropriate yields are bracketed in Table 2.

TABLE 2. *Yields per Acre in lb. of Dry Matter*

	Tippings	*1st year*	*2nd year*	*3rd year*	*3-year total*
Potash					
lb. per acre					
0	312	518	952	672	2,142
20	309	509	932	653	2,094
40	317	517	961	670	2,148
Nitrogen					
lb. per acre					
0	296 }	502	878 }	582 }	1,962 }
20	316 }	516	942 }	672 }	2,130 }
40	326 }	527	1,025 }	742 }	2,294 }
Nitrogen type*					
Blood	319	523	990	701	2,214
Cyanamide	316	518	967	688	2,173
Sulph. ammonia	328	523	994	732	2,249

* Means of all plots irrespective of quantity.

TABLE 3. *Analyses of Variance (Mean Squares)*

	df.	*Tippings*	*1st year*	*2nd year*	*3rd year*	*Total*
Nitrogen regression	1	} 28·34	38·38 } 19·29	1343·22 } 674·86	1607·88 } 807·98	6861 } 3430
Deviations	1		0·20	6·49	8·09	—
Potash	2	2·39	2·89	27·96	13·26	107
K×N interaction	4	20·10	3·18	32·69	14·76	113
Quality N	2	2·82	0·68	18·22	41·76	115
Error	38	8·06	12·13	35·86	35·24	195
Blocks	5	59·01	76·98	306·65	524·68	1630
Total	53					
z. nitrogen quantity effect		0·6287	0·5760*	1·8116*	1·9102*	1·7803*
z. significant P. 05		<0·5994	>0·6933	<0·7141	<0·7141	<0·7141

* Value for nitrogen regression.

Neither potash nor type of nitrogen had any significant effect upon yield; for potash this confirms current tradition, but for type of nitrogen the exact opposite is the case. Not only are the total yields for the three nitrogen classes, blood-meal, cyanamide, and sulphate of ammonia equivalent within the limits of error, but the shape of the yield-curves (not reproduced here) remains identical throughout the three-year cycle, notwithstanding the very rapid fluctuations from low to high yield due to climatic factors. As a typical instance of this identity of behaviour, the

data for a short-period seasonal rise in crop-yield that occurred between the 36th and 40th plucking rounds are:

Plucking round	*Blood*	*Cyanamide*	*Sulphate of ammonia*
36	12·52	11·75	12·27
40	53·67	54·61	52·97

This experiment gives, therefore, no support to the theory that, owing to their rapid availability, the use of so-called 'soluble' nitrogenous fertilizers engenders periods of rapid and excessive flushing, followed by exhaustion of manurial resources. This theory has to a large extent influenced agricultural practice in the past. Yet prior to this confirmation in the field, Joachim's results on nitrification [5] had shown that differential rates of availability and loss as between inorganic nitrogenous substances and organic types with low carbon-nitrogen ratios, were virtually non-existent.

In the first year, the tippings show a definite response to nitrogen applications, but this response is not continued in the 'flush' harvests that follow. This apparent cessation of effect must be viewed in relation to the special circumstances of growth in that year. In addition to producing tippings and flush, nitrogen has been used in building up the foliage and frame of the bush from the pruning level, and only part of this growth is accounted for as tippings. Tubbs, on the basis of a regression, has shown that this new growth amounts to three times the tipping yields (private communication). In comparison with later years, therefore, less of the added nitrogen is available for flush production in the last half of the season, so that a diminution in response is not at all anomalous.

The second and final years of the cycle show substantial gains due to applications of nitrogen, and their interest lies largely in the very close relationship between quantity applied and yield produced. In fact, as the analyses of variance show, the nitrogen effect is almost entirely accounted for by the linear regression, all deviations being insignificant compared with the error figure. It is unusual to find so exact a response in agricultural practice, but tea cultivation possesses features which place it in a class apart from ordinary crops. In the first place, the produce is entirely vegetative and the relationship between growth and crop is thus very much simplified. In addition, the frequent plucking artificially maintains an active vegetative phase and provides a continuous stimulus to growth. The demonstration is further helped by the lack of response to potash and the consequent absence of interactions. Whatever general statement of nutrient-growth relationship may emerge at some later date, whether sigmoid or logarithmic in form, so striking a linearity in response of tea to nitrogen suggests that the applications used are some way below the optimum, and that there is little fear of reaching saturation-point unless excessive doses are applied.

The Behaviour of the Crop in Successive Years

Within the natural unit of the pruning cycle, seasonal effects and cultural operations divide the time period into definite yearly periods. In

the second and third years the crop yields have shown a superficial similarity in response to nitrogenous dressings and failure in response to potash. In addition, it is of some interest to examine the permanence of the production effects on blocks and individual plots as the pruning cycle advances. A more detailed knowledge of all these points is obtainable by considering the correlations between yield in successive crop years. By means of the analysis of covariance the correlations are divisible into the same categories as have been used in considering variance.

In addition to the yields for the three experimental years, data were available for thirteen plucking rounds from the year preceding the start of the experiment proper. These results had been collected at the end of the previous pruning cycle to give evidence of the general degree of heterogeneity of the experimental area. In using these figures the plots have been grouped according to the treatments assigned later. The correlations between each experimental year and its predecessor are given in Table 4.

TABLE 4. *Correlation between Successive Experimental Yields*

	1st year and uniformity trial	*2nd year and 1st year*	*3rd year and 2nd year*	*Significant value P ·05*
Nitrogen treatments	−0·818	+0·990	+0·990	0·997
Potash treatments	+0·975	+0·949	+0·917	0·997
Interactions	+0·233	+0·522	+0·916	0·878
Blocks	−0·318	+0·404	+0·816	0·811
Error	+0·292	+0·818	+0·768	0·304
Total	−0·026	+0·613	+0·848	<0·273

Owing to the few degrees of freedom allocated to the treatment effects, none of the treatment correlations is significant except that for interactions in the third year; and since these interactions are themselves insignificant this correlation gives no specific information regarding treatments.

The remaining correlations for the first year and the uniformity trial are also below the significant value. There is accordingly no evidence that the early development of a bush or plot after pruning is closely related to its crop status in the previous cycle. The pruning operation that intervenes between the two croppings, though it is naturally a levelling one, imparts a certain individuality to the bush (thus providing it with a new datum-line of growth), but the absence of definite correlation between parallel plots, shown by the error correlation, is to some extent unexpected. It suggests that the major cause of heterogeneity in tea experiments lies not in soil differences, which might be expected to persist from one cycle to another, but in variable bush response to standard cultural operations.

When no such highly individualistic treatment as pruning intervenes, the correlation between parallel plots in successive years reaches important dimensions and the error correlations for the second-first and third-second periods show definite significance.

The block correlations are of particular interest in this series; the value $+0{\cdot}404$ between second and first years is small enough to be due to chance causes and only in the last year does significance emerge. The indications are that the status of blocks relative to one another has changed during the cycle, and, since there is no reason to suspect any changing soil or other factor, the cause must be sought in intrinsic bush characteristics. An examination of the data showed that a large part of this alteration in rank of blocks was due to one of the six blocks comprising the experiment. The block in question was relatively low-yielding at the beginning of the experiment, being 13 per cent. below the experimental mean. By the middle of the second year its yield was normal and when the pruning cycle was complete it was nearly 25 per cent. better than the mean of the experiment as a whole. In order to pursue the matter further, the individual pluckings were amalgamated into sets of five, and the regression of the percentage deviation of this block from the mean of all, calculated on time in the cycle. The resulting linear equation was

$$Y = 1{\cdot}913X - 14{\cdot}67,$$

where Y is the deviation from mean block yield and X the time in periods of 45 days from the start of the experiment. This block has apparently increased in yield at a rate of nearly 2 per cent. of the mean every five pluckings. The regression coefficient is highly significant when tested by means of t (P ·01).

It so happened that a portion of the field used for the experiment was planted with tea which showed a minor difference in race or jat characteristic, and the block in question was the only one on that portion. No difference in response to manures has arisen on this account, but the divergence in growth seems to be directly attributable to this jat difference. The term jat carries with it no well-defined genetical implications, and is not a synonym for variety. No attempt has been made to breed pure lines of tea, and seed-gardens are seldom if ever protected from the possibility of cross-fertilization. Any field of tea includes bushes of varying morphological characteristics mainly associated with leaf-shape, colour, number and type of indentations and leaf-size, and the existence of these variations is the usual basis for deciding on jat distinctions. In fact, tea derived from different tea-seed gardens is commonly dignified by assigning to it different jat names. On the other hand jats do exist which are easily distinguishable by reason of well-accentuated morphological differences, such as those classed as China jat, Manipuri jat, or light-leaved Assam jat. That considered here had no external distinguishing feature except a slightly brighter and larger leaf.

The importance of this finding is both general and particular. Associated with what has been loosely called jat difference, we have in this difference of yield-distribution in the cycle a definite and measurable growth characteristic. In particular, the cultivation of this or similar jats might on this basis be reasonably extended beyond the three-year cycle and still maintain a high yield. The present tendency in Ceylon is towards an elongation of the pruning cycle in high-grown tea for reasons of quality unassociated with yield, but the choice of fields for this purpose

which are capable of giving adequate returns in the later stages of growth should not be neglected. In the early stages of the pruning cycle the leaf harvested does not produce fine tea. A jat which produces minimal yields at this stage, and more generous yields than the average in the later years, is of particular interest.

Yields of Foliage-Leaf and Wood

In addition to yields of flush for manufacture, some account must be taken of the rest of the growth produced during a pruning cycle. This consists of branch and leaf, almost all of which is removed at pruning time; the leaf normally returns to the soil, but the woody portions are permanently removed, and represent an appreciable part of the drain on the sources of fertility.

Previous figures for pruning weights and composition have been deduced from such small samples as to be entirely misleading. Thus Bamber [6] calculated yields per acre on a twenty-bush basis, and obtained values more than five times those derived from the present investigation.

Since the weighing of prunings from an area of $4\frac{1}{2}$ acres is not a practicable proposition, a sampling method was employed. The maximum sample number that could be reasonably dealt with, allowing for the necessity of obtaining dry weights, was 25 per plot. This gave a unit of 150 for each treatment, 450 for units representing different levels of nitrogen and potash manuring considered separately, and 1,350 in all. The system of sampling was to choose by random numbers a row and a bush in that row, and to prune five consecutive bushes. Five such selections were made for each plot. The samples were dried for a month with conditioned air, after which the leaves were stripped and the foliage and wood weighed separately for each plot. For purposes of reduction to an acreage basis, 3,000 bushes per acre were taken as the standard: the yields are appended in Table 5.

TABLE 5. *Yields per Acre in Pounds of Leaf and Wood removed in Pruning*

	lb. N applied per acre			*lb. K_2O applied per acre*		
	0	*20*	*40*	*0*	*20*	*40*
(1) Foliage-leaf .	1,547	1,560	1,761	1,549	1,668	1,651
(2) Wood . .	2,052	2,177	2,514	2,161	2,284	2,298

(1) Significant difference 183 = 11·3 per cent.
(2) ,, ,, 350 = 15·9 per cent.

The errors are unavoidably high, but the appropriate z and t tests show that both leaf and wood have responded to nitrogen, the effect being marked with the heavier dose. The response to potash is left in doubt owing to the high error, but it does not exceed 6·5 per cent. In the main, the frame of the bush has responded to manurial applications in the same fashion as the flush. Any exact statement of the relationship between flush and foliage-growth is precluded by the smallness of prun-

ing samples from the individual plots, and this rendered nugatory the attempt to establish such a relation by the analysis of covariance. The residual correlations for individual plots were negligible, being

$$r \text{ Flush, foliage-leaf} = +0{\cdot}063 \text{ and } r \text{ Flush, wood} = +0{\cdot}023.$$

Utilization and Recovery of Nutrients

The yields discussed in the previous sections, taken in conjunction with details of the composition of the several types of materials involved, provide a partial picture of nutrient removal from the soil, and an index of the recovery of added nutrients. With a perennial bush-crop under a semi-permanent experiment, yield data for roots and the unpruned portion of the stem cannot be obtained without destroying the continuity of the experiment. There is no doubt, however, that the flush, foliage-leaf, and wood yields assessed in the previous sections, constitute by far the greater portion of the growth experienced during a pruning cycle.

Dealing first with the nitrogen balance of the crop, analyses revealed that differences in nitrogenous manuring produced no significant difference in the total nitrogen, potash, or phosphoric-acid content of the constituent parts, and accordingly a general mean value from all plots has been used. Since the composition of the 106 separate flush harvests was not known, recourse was had to an adopted mean for 35 sample harvests.

The figures for foliage-leaf and wood were derived from the analyses of the actual samples. The mean compositions are set out below:

Composition of Crop (per cent. on Dry Matter)

	Nitrogen	*Potash*	*Phosphoric acid*
Flush	4·09	1·63	0·85
Foliage-leaf . . .	2·02	1·06	0·35
Wood	0·85	0·53	0·19

When combined with recorded yields the total quantities of nitrogen consumed are those tabulated in Table 6.

TABLE 6. *Removal of Nitrogen by Crop, in lb. per Acre*

	Plots receiving nitrogen per acre (in 3 years)		
	Nil	*60 lb.*	*120 lb.*
Flush	80·2	87·1	93·8
Foliage-leaf . . .	31·2	31·5	35·5
Wood	17·4	18·4	21·3
Total	128·8	137·0	150·6

Incremental differences, 8·2, 13·6.
Total recovery 21·8 = 18 per cent.

In each case the flush accounts for nearly two-thirds of the nitrogen used. The differences in nitrogen consumption due to manuring are small, and their total, 21·8 lb., is but a small fraction of the quantities supplied as manurial rations. When every reasonable allowance has been made for nitrogen absorbed in thickening of the permanent frame and in new root-growth, the recovery of nitrogen is seen to be poor in the extreme. These figures have the effect of putting into striking contrast the relative dependence of the crop on soil and manurial resources respectively. The literature of tropical crops is peculiarly lacking in examples of data depicting manurial recovery. Magistad and Oliveira report a recovery of 23 per cent. of manurial nitrogen in pineapples [7], whilst Haigh and Joachim [8] have observed as high a recovery as 70 per cent. for paddy, a crop that is atypical because of its direct assimilation of ammonium compounds. In view of the linear increments in yield shown by the present experiment, the low recovery of 18 per cent. cannot be attributed to a saturation effect, and other causes must be sought. It appears reasonable to ascribe the main source of loss to the high temperatures, high rainfall and bare soil, despite the fact that the continuous growing-period in tea in Ceylon places the crop in a very favourable position for assimilation of manurial supplies.

By way of comparison with temperate crops, the figures of Russell for the classical experiments at Rothamsted may be quoted [9]:

	Percentage recovery of nitrogen at Rothamsted
Wheat	33
Barley	48
Swedes	18
Mangolds	57
Sugar-beet	57

Allied to the question of recovery of added nutrient is that of the constant drain upon the sum total of the nutrient resources brought about by the annual removal of the crop. For a yield of 2,100 pounds distributed over a three-year pruning cycle the utilization of nitrogen, potash, and phosphate is as follows:

TABLE 7. *Removal of Nutrients by a 2,100 lb. Crop (in lb. per Acre)*

	Nitrogen	*Potash*	*Phosphoric acid*
(1) Flush	87	35	18
(2) Wood	19	12	4
(3) Foliage	33	17	6
Total	139	64	28
Permanently removed (1 and 2)	106	47	22
Quantity removed per annum	35	16	7

In relation to current agricultural practice these figures are instructive. There has been of late a tendency in Ceylon to curtail manurial supplies of potash, and on the other hand to employ large doses of phosphoric

acid amounting to as much as 120 lb. per acre in a three-year cycle. Viewing manurial practice as an effort to maintain soil fertility and to produce extra crop, it appears that phosphoric applications are probably in excess, and that despite a lack of response to potash, its curtailment may lead to a state of deficiency if this policy is indefinitely continued. The maintenance of mineral resources in relation to immobilization of supplies by a quasi-lateritic soil has been made the object of work now proceeding in the ensuing cycle of the experiment.

Summary

1. Results are described from a field experiment on tea, carried out over a complete three-year pruning cycle, to investigate the response to increments of nitrogen and potash manures, and the respective values of organic and inorganic sources of nitrogen.

2. The data show that potash produced no significant effect on 'flush', foliage-leaf, or wood-growth, but that nitrogen gave substantial responses in each constituent. The yields of flush indicate response only in the second and third years, and this response is to all intents a linear function of manurial application. There is no indication that up to the maximum dose used (40 lb. per acre) saturation effects have occurred.

3. There was no difference between the three types of nitrogen used (blood-meal, sulphate of ammonia, and cyanamide).

4. Correlations between yields in successive years showed that specific differences in yield-status of parallel plots are not maintained when pruning intervenes between the two years considered, and that bush heterogeneity is more important than soil heterogeneity as a cause of variability.

5. Where a difference in race or jat occurred in the experimental tea, it was characterized by a distinctive difference in yield-distribution during the cycle.

6. A balance-sheet of nutrients absorbed shows a low recovery of nitrogen from manurial applications not exceeding 18 per cent. on the average. An average crop of 700 lb. per acre removed annually 35 lb. nitrogen, 16 lb. potash, and only 7 lb. phosphoric acid. These quantities are discussed in relation to the maintenance of soil fertility and current practice.

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APPENDIX

THE EFFECT OF MANURIAL TREATMENT ON THE COMPOSITION OF THE MADE TEA

Completed by T. EDEN *from an investigation begun by* D. I. EVANS

The quality of manufactured tea has always been a paramount consideration in tea culture, and in planning the routine of crop management, and in introducing any novel feature, the possible effect on quality is continually in the mind of the agriculturist. There is at the present moment no more vigorously contested aspect in the technology of tea than the effect of manuring on the finished product.

Quality in tea wellnigh eludes definition. It is generally held to be the resultant of a number of more or less ill-defined characteristics in the liquors, chief among which are the colour, strength, pungency (astringency), and flavour.

These characteristics, which are of a purely qualitative nature, are assessed by the tea-taster with a remarkable degree of success when the differences are very pronounced, but it would be idle to deny that the subjective element plays a great part when fine distinctions are drawn.

In order to rationalize the whole matter, two lines of attack are necessary: (*a*) a study of the constituents of made tea, and (*b*) a quantitative or quasi-quantitative standardization of the tea-taster's technique. Both these aspects have received attention, but sufficient progress has not been made in the second for a correlational study with chemical data to be made with any degree of reliance. These circumstances notwithstanding, since the ultimate aim is that of interpreting quality in terms of chemical and physical standards, it is of importance to determine whether manuring causes any consistent difference in the composition of made tea.

Every individual harvest of the foregoing experiment has been manufactured on specially designed experimental machinery. Over the three-year period a comparison has been made between tea from plots receiving no nitrogenous manure and those to which 40 lb. per acre of nitrogen had been applied annually. In the last year of the experiment a distinction was drawn between the type of nitrogen applied, and leaf from plots manured with equivalent quantities of nitrogen as sulphate of ammonia, cyanamide, and blood-meal was simultaneously manufactured.

Analytical Determination and Methods

The analytical data were all determined on the liquors and are all expressed in terms of dried tea. In choosing what characteristics in the liquors should be determined, account was taken of similar work done elsewhere and particularly of those compounds which are normally extracted in large quantities by the ordinary domestic infusion. Evans [1] has shown that the non-tannin substances are almost completely extracted at the end of five minutes, and that a second infusion contains little caffeine and hardly any ash-constituents. Tannins are less readily extracted, though they form the largest individual constituent. Taking the five-minute infusion as the standard, the increased extraction obtained

by doubling the time of infusion, as given by him, is—soluble substances 11·5, tannin 21·0, nitrogen 7·0, and other substances 3·0 per cent.

The following are the determinations made and the methods used:

Soluble substances (*extract*). Two gm. of crushed tea (passing the 20-mesh sieve) are boiled with 400 c.c. of distilled water under a reflux-condenser for 45 minutes. The contents, allowed to stand over-night, are then made up to 500 c.c. in a graduated flask. Filtered aliquots are taken for all subsequent determinations. For soluble substances 50 c.c. are evaporated to dryness on a water-bath and subsequently kept in a drying-oven at 105° C. for 2 hours.

Tannins. The estimation of tannins in tea is not easy, and a thoroughly satisfactory method has still to be worked out. It is significant that the latest monograph on vegetable tannins gives no method for their estimation [2]. After experience with precipitation methods by means of formaldehyde [3], and with the official method of the Association of Official Agricultural Chemists [4], which has a very elusive end-point in titration, recourse was had to a modification of Shaw's iodometric technique [5]. The chief alteration is a lengthening of the time of reaction from 15 to 90 minutes. The determination consists in assessing total oxidizable matter in the first place, after which the tannins in a further aliquot are precipitated by the standard gelatin reagent and kaolin method and a further iodometric oxidation made on the filtrate. The difference is recorded as tannin equivalent. Of these two determinations the latter is the least satisfactory owing to difficulties in the standardization of precipitation. If, however, a highly significant relationship exists between total oxidizable matter (T.O.M.) and oxidizable matter minus non-tannins, it would be simpler and more satisfactory for comparative purposes to use some appropriate function of the figure for total oxidizable matter.

In order to explore this possibility, the regression of tannin on total oxidizable matter was examined on a set of fifty-eight determinations of these teas. The resulting linear equation was

$$Y = 0{\cdot}783X - 0{\cdot}30,$$

where Y = tannins determined from the two afore-mentioned oxidations, and X = total oxidizable matter.

The standard error of the regression coefficient was 0·035, so that the goodness of fit is very satisfactory. Since the line so nearly passes through the origin, the oxidizable matter ascribable to tannin bodies is to all intents and purposes proportional to T.O.M.

This figure thus provides an easily determined value for comparative purposes. The chemical procedure is as follows:

Total oxidizable matter. To 20 c.c. of the extract, an equal quantity of N/10 iodine is added, together with 12 c.c. of N-sodium hydroxide. After a lapse of 90 minutes, 25 c.c. of sulphuric acid (40 gm. per litre) and 600 c.c. of water are added. The liberated iodine is titrated against N/20 sodium thiosulphate. The results are expressed as titre in c.c. per one gram of the original sample.

Oxidizable matter (*non-tannins*). The method followed was that of the

A.O.A.C. (loc. cit.) with the addition that further additions of kaolin were made, and further shaking carried out, until no opalescence occurred when the filtrate was tested with dilute tannic acid.

Nitrogen in extract was determined by the Kjeldahl method.

Caffeine was determined by the Bailey-Andrew method (A.O.A.C.).

Ash. Ignitions were made in platinum ware.

Composition of the Teas

The mean composition of the teas for the first comparison, i.e. no nitrogen versus 40 lb. per acre of nitrogen is given in Table 1. The number of samples for analysis was reduced by bulking together a number of consecutive harvest samples in quantities proportional to their yields. For extract, nitrogen in extract, and T.O.M., there were finally sixteen weighted samples of five; for caffeine and ash the samples covered ten consecutive samples.

TABLE 1. *Comparison of Tea receiving no Nitrogen and Tea receiving 40 lb. of Nitrogen per Acre*

	No nitrogen	*With nitrogen*	*Difference*	*Standard error*
* Extract	41·44	41·46	−0·02	0·078
*N. in extract	1·61	1·67	**−0·06**	0·00012
‡T.O.M.	233·9	232·1	+1·8	1·158
*Caffeine	3·14	3·25	**−0·11**	0·034
*Ash	5·25	5·16	**+0·09**	0·034

* Per cent. on dry tea. ‡ Titre per gram of dry tea.

Such differences in composition as the data show are all very small. Of the five characteristics studied, only three attain statistical significance. In soluble nitrogen and the closely related caffeine, the teas manured with nitrogen show a consistent superiority. Although it is interesting to note that nitrogenous manuring affects caffeine-content, which some regard as a mobile form of storage for nitrogen, the difference is not large enough to be technologically important [6]. Neither extract nor tannin is appreciably affected by the manurial differences. Ash, on the other hand, shows a small but significant superiority in the no-nitrogen group. So far as composition is concerned, there is nothing in the data to warrant the view that nitrogenous manuring in the quantities here illustrated has any detrimental effect upon the finished product.

A similar procedure was adopted for the samples embodying different forms of the same quantities of nitrogenous manure. In like manner bulked samples of five were examined. The significance of treatment effects has been tested by a comparison of treatment variance with the interaction of treatment with occasion. Using Snedecor's function F, the ratio of the comparable variances, the actual and the significant values for each characteristic are tabulated for comparison [7]. The replication is sevenfold throughout.

Not one of the differences is statistically significant. As with yielding capacity, so with composition of the finished product, the various forms of nitrogen behave alike. The agricultural preference for so-called

'organic' nitrogen as manure is not substantiated by differences in composition of the liquors under otherwise comparable conditions.

TABLE 2. *Comparison between Different Kinds of Manurial Nitrogen*

	Sulphate of ammonia	*Cyanamide*	*Blood-meal*	*F*	*F signif.*
Extract	44·24	44·12	44·26	1·87	19·41
N in extract	1·69	1·63	1·62	1·39	3·88
T.O.M.	259·3	263·4	262·4	3·37	3·88
Caffeine	3·28	3·28	3·25	1·58	19·41
Ash	5·33	5·28	5·26	1·09	3·88

Summary

1. Two series of samples of made tea, derived from field experimental plots, have been examined for chemical composition.

In the first series a comparison was made between tea receiving no nitrogen and tea receiving 40 lb. nitrogen per acre; the samples extended over a three-year pruning cycle.

In the second series a comparison was made between equivalent quantities of nitrogen in three forms, sulphate of ammonia, cyanamide, and blood-meal, in the third year of treatment.

2. The methods of analysis used are described.

3. The results show that nitrogenous manuring makes distinguishable but unimportant differences in the soluble nitrogen, caffeine, and ash, but that extract- and tannin-contents are indistinguishable.

4. No significant differences in any characteristic emerged from the comparison of different kinds of nitrogen.

Some two-thirds of the chemical determinations in this paper were made by Dr. D. I. Evans prior to his severing connexion with the Tea Research Institute, and the chemical technique followed throughout is his. The remainder and the statistical analysis of results and their interpretation are the sole responsibility of the joint signatory (T.E.).

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THE CULTIVATION OF RICE IN CEYLON

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With Plate 11

UNLIKE the plantation industries of tea, rubber, and coco-nuts, for which complete statistical information on areas and yields are available, there are in Ceylon no reliable data on village agriculture. It is estimated that about 800,000 acres of rice are grown annually, the actual area of land being less, as some land carries two crops a year. The latest official estimate of yield by revenue officers is 14 bushels (of 45 lb.) per acre. This figure is admittedly open to serious error, and since 1925 figures for yield have not been included in the statistics. There is reason for supposing that the estimated yield of 14 bu. per acre is too low, and this question will be referred to later. If the average yield is taken to be 20 bu., the annual production is 16 millions bu. of paddy (rice in the husk) or 8 million bu. of husked rice. This is equal to about 4·6 million cwt. The imports of paddy and rice into Ceylon for the five years 1929–33 in terms of husked rice have averaged 9·27 million cwt. It will be seen, therefore, that Ceylon produces about a third of the rice it requires. Why a purely agricultural country like Ceylon finds it necessary to depend on Burma for two-thirds of its rice requirements is due to the magnitude of the plantation industries, particularly of tea and rubber, and to some extent of coco-nuts. Not only do the plantation industries make use of land much of which could grow rice or other cereals, but they employ a large labour force whose staple diet is rice. It must be added that it is to its plantation industries that Ceylon owes its prosperity.

In spite of the large areas under tea, rubber, and coco-nuts, there are larger areas of jungle, scrub jungle, and savannah capable of growing rice if irrigation-water can be supplied. The construction of new works for the supply of irrigation-water on a large scale will be costly and possibly uneconomic, but the production of rice can be and is being increased by the following means: (i) the restoration of ancient village tanks where old paddy land exists and where there is still a nucleus of population; (ii) the improvement of major irrigation-works and the construction of new channels to bring more land under cultivation; (iii) organized colonization schemes under major irrigation-works, where owing to malaria or other reasons land has not been taken up; and (iv) the adoption of improved methods of cultivation, which are being vigorously urged by the Department of Agriculture through propaganda and practical demonstration, and include the use of pedigree seed, improved implements, of green, farmyard and artificial manures, and the adoption of transplanting in those areas where this practice is suitable.

Climate and soils.—Rice is chiefly cultivated in the low country, but considerable areas are cultivated in the mid-country up to 2,500 ft. above sea-level. Rice is cultivated between 4,000 and 5,000 ft., but the area is small. The temperature conditions for the bulk of the rice area do not

vary greatly. There is, however, considerable variation in the rainfall. Rice is grown all over Ceylon and the rainfall varies from under 50 in. to over 200 in. Under favourable conditions from 50 to 60 in. of rain distributed during the growing-season are sufficient for a 4-months' crop. More than half of Ceylon has a yearly rainfall of under 75 in., and in this part of the Island cultivation that depends entirely upon rainfall is precarious owing to the uncertainty of its incidence. Irrigation-water is generally utilized both to supplement and, in the dry season, to replace direct rainfall. Even in the wetter parts of the Island the run-off from land adjoining the rice fields is utilized. Owing to the risk of floods in the wet season large areas are cultivated under irrigation during the dry season. Generally speaking, there is sufficient rainfall for rice during both the north-east and south-west monsoons only in a small area in the south-west of the Island stretching, roughly, from Kandy in the mid-country to Galle at sea-level. But even here run-off from nearby land is utilized. During the north-east monsoon 5–6½ months' varieties are grown, and during the south-west monsoon 4–5 months' varieties. The seasons are known, in Sinhalese, as *maha*, and *yala* respectively, meaning long and short season. In the rest of the Island direct rainfall is insufficient during the south-west monsoon, when generally 3-months' varieties are grown under irrigation. During the north-east monsoon 4-months' varieties are generally grown, to some extent with direct rainfall only, but generally with supplementary irrigation-water. Table 1 gives an idea of the meteorological conditions in two dissimilar parts of the Island.

No systematic study of the rice soils has yet been made. Typical soils are clays or clay loams that can be puddled to retain water, and have an acid or slightly acid reaction. In the Eastern Province there are considerable areas of sandy-loam soils which produce a good crop when water is sufficient.

Irrigation.—Most of the paddy land is irrigated with water stored in large or small reservoirs, known as tanks. The thousands of tanks, most of them abandoned for centuries, in the northern half of the Island, bear witness to the magnitude of the facilities for irrigation in ancient times. Many of these tanks were constructed before the beginning of the Christian era, and modern engineering science is impressed by the ingenuity displayed in the construction of them and their channels. The channel from Kalawewa tank to Anuradhapura is 57 miles long. There were systematic irrigation schemes and small tanks were fed from large tanks. Most of the thousands of tanks are small, but many were (and are) large. The area of Minneriya tank, the largest, is 4,500 acres; Kalawewa, the second largest, covers 4,337 acres, and Nachchaduwa tank 3,920 acres. There is evidence for the statement frequently made by Ceylonese that at one time Ceylon was the granary of the East.

Most of the modern major irrigation-works are based on ancient tanks that have been restored and improved, and many of the ancient channels have been utilized. The area of land under major works actually sown in 1933 is given as 167,000 acres. Some of the area is cultivated twice a year, so the actual land area is somewhat less. Under smaller village tanks in the same year the area is given as 212,941 acres. Thus nearly half the total rice area is irrigated by major works or by village tanks.

TABLE 1. *Rice Cultivation; Meteorological Data*

District	*Month*	*Total no. of days*	*Mean monthly temp. ° F.*	*Maximum temp. ° F.*	*Minimum temp. ° F.*	*Mean daily sunshine hrs.*	*Rainfall in.*
Batticaloa, 30 ft.	Mar.		80·2	87·6	69·7	8·4	3·15
a.s.l., SW. Season,	Apr.		82·0	90·6	74·8	8·5	1·95
3-months rice.	May		83·6	96·2	74·6	8·0	1·84
Vellai perunel.	June	90	84·8	97·7	74·6	7·5	0·96
Irrigated.							
Batticaloa, 30 ft.	Oct.		80·9	88·6	72·1	7·5	6·49
a.s.l., NE. Season,	Nov.		79·4	90·1	72·1	6·4	13·51
4-months rice.	Dec.		77·9	84·1	70·5	5·8	16·46
Perillanel.	Jan.		77·6	82·4	69·8	6·7	10·36
Irrigated when	Feb.	120	78·3	87·2	67·4	8·5	3·44
necessary.							
Kandy, 1,611 ft. a.s.l.	Apr.		78·7	89·4	65·8	6·3	6·83
SW. Season, 4½–5-months rice.	May		78·3	91·1	67·6	5·7	5·78
	June		77·0	88·1	66·2	4·1	9·45
Suduhinati.	July	about	76·6	85·5	67·3	4·4	7·39
Irrigated when	Aug.	140	76·2	88·7	67·2	4·7	5·82
necessary.							
Kandy, 1,611 ft. a.s.l.	Sept.		76·2	86·6	64·5	5·5	6·05
NE. Season, 6–7-	Oct.		76·0	87·1	65·1	5·1	11·62
months rice.	Nov.		75·9	86·0	62·2	4·7	10·51
Mawi.	Dec.		75·2	85·8	61·8	5·5	8·85
Irrigated when	Jan.		75·0	85·7	63·4	6·1	5·38
necessary.	Feb.	about	76·6	88·4	53·3	7·0	2·23
	Mar.	200	78·4	89·2	64·1	6·9	4·20

Notes. (1) The figures given are means over a number of years.
(2) In the Batticaloa District sowing during the NE. monsoon generally takes place early in November.
During the SW. monsoon, when irrigation-water almost alone is relied on, sowing takes place from February to June, but a common time for sowing is from March to April.

Varieties.—Lists have been published of over 300 different names of botanical varieties, but there can be little doubt that many are synonyms. A complete study of the varieties has not yet been made, but those so far examined by Lord and Abeysundera [1] show that the *mawi* (aged 6 months) group of rices are similar to the Burma *midon* type, and the short-aged (3–4 months) rices like *hinati*, *murungan*, *hinkarayel*, *illankalayan*, and *suduhonderawala* (5 months) are similar to the Burma *ngasein* type [2]. A small round-grained variety known as *podiwi* (similar to the Indian *muthusamba*) with a white testa is grown on a small scale and is esteemed as a table rice. The striking peculiarity of Ceylon rices compared with rices in other countries is that they have almost invariably a red testa. Most of the varieties grown on a large scale are unawned.

There is a belief among cultivators that certain varieties are best suited for certain soil conditions, but it is remarkable how well one variety will adapt itself to different soil and climatic conditions. The pedigree selec-

tion *perillanel* 26014 may be quoted as an example. This selection gives comparatively high yields on sandy soils at Batticaloa at sea-level and on clay loams in the Province of Uva at 2,000 ft. above sea-level. Another pedigree selection, *vellai illankalayan* 28061, has proved to be a higher yielder than the village varieties over most of the northern half of the Island. There is little doubt that the number of so-called varieties at present grown could be divided by ten without loss of yield and with a very definite gain in uniformity.

Unfortunately, in a country like Ceylon, with large differences in rainfall, different-aged varieties are essential. A variety for a district depending upon direct rainfall must be of such an age that it will flower during a period of light rainfall and mature in a comparatively dry period. The time of sowing cannot be altered very much; it depends on the start of the rains. Under irrigation it is the general custom to grow a 3-months' variety during the dry season and a 4-months' variety during the wet. Other things being equal, the yield of a variety is positively correlated with age.

There are now available for most of the different conditions under which rice is grown in Ceylon, pedigree selections yielding from 15 to 30 per cent. more than the local village varieties. The technique used in selection has been described by Lord [3]. These pedigree selections are now becoming popular with cultivators. Most of the rice produced is husked in a primitive mortar in the home. Until a milling industry using modern machinery is developed, there is no reason why the present red rices should be replaced by white.

Size of holdings.—Here, too, no reliable statistics are available, but it is believed that the size of the holding worked by one man is from 2 to 3 acres. This does not apply to the Eastern Province where holdings of over 25 acres are common and where one man will work from 5 to 7 acres. The small size of the holdings, apart from the Eastern Province, is due to lack of land and the popularity of paddy cultivation among the Sinhalese, who consider that more prestige is attached to this than to other forms of manual work.

In the east and north of the Island comparatively large rice-fields are found, many being as large as half an acre and a few slightly larger. Even here the tendency is to construct small fields rather than to undertake the necessary levelling of the land to construct large fields. In the rest of the Island rice-fields are very small, and many of the picturesque terraced rice-fields in the mid-country are no larger than 10 or 12 sq. ft.

Cultivation.—In small fields the land is tilled by hand with an implement known as a 'mamootie', which is a heavier and larger variety of hoe. It produces the same effect as digging with a spade, the necessary force to penetrate the ground being obtained by swinging the implement over the head. In larger fields tillage is done either by a primitive plough drawn by cattle or buffaloes, or by the trampling of a team of six or eight buffaloes driven round and round the field. The latter method is chiefly used on marshy land where animals sink in up to their bellies, and on flooded land where it is difficult to see where the plough has been. But in many places fields are prepared by trampling that could easily

be ploughed, because buffaloes cost less than plough cattle. Plough cattle are small and generally uncared for, but many are quite able to draw a light mould-board plough like Ransomes 'Ceres' or 'P.I.K.' The comparatively high cost of these ploughs, however, precludes their general use. A simple wooden harrow pulled by two bulls is used in Burma to puddle the soil after the first ploughing. The writer has introduced this implement into Ceylon, but it has not yet become very popular. Its use ensures better and cheaper puddling of the soil. After two or three ploughings or tramplings with one or two inches of standing water on the soil, the field is levelled either by hand-levellers resembling a wooden rake without teeth, or by a plank drawn by two cattle. About this time the bunds surrounding the field are generally plastered with mud from the field to fill up crab holes and to render the bunds more impervious to water. After levelling, small drains are made to remove any standing water. Germinated seed is broadcast at the rate of from $2\frac{1}{2}$ to $3\frac{1}{2}$ bushels per acre. In germinating the seed it is first soaked in water (in a gunny bag) for 12–24 hours, after which the bag is put in a shed and covered with moist empty bags or with leaves. Sometimes light weights are placed on the top. After from 4 to 7 days, when the radicle and plumule have emerged, the seed is sown. In parts of the Eastern and Northern Provinces appreciable areas are sown during the NE. season with ungerminated seed. The rather sandy fields are ploughed, without flooding, at the start of the rains, and irrigation water is not issued until the rainfall has become inadequate. With good cultivation 2 bushels per acre of seed paddy are ample.

The seed used is mainly that grown during the last corresponding season, which means that the seed is from 5 to 8 months old. The germination rapidly lessens after 10 months from harvesting. Newly harvested rice seed, except the seed of dead-ripe, short-aged, varieties cannot be used for sowing until 2 or $2\frac{1}{2}$ months after harvest.

As a result of the propaganda efforts of the Department of Agriculture, the acreage transplanted, though small, is increasing. Experiments in Ceylon [4, 5] have shown that, with a 6 to 7 months' rice, transplanting increases the yield by from 30 to 46 per cent., and is profitable. With the 3- and 4-months' varieties, which occupy most of the rice area, it is doubtful if transplanting will be profitable. Weeding, with or without thinning the plants, a month after sowing, is carried out in a few districts only. Manuring will be discussed in the following section. The crop is harvested about one month after flowering by means of a serrated sickle-shaped knife. It is threshed by trampling with buffaloes, and winnowed by wind. Threshing is done on the field or on adjacent high land, and although in many places threshing floors are carefully beaten flat and plastered with cattle-manure, frequently the floors are roughly made, and the rice from these floors contains sand and small stones, which are objected to by consumers as they cannot easily be removed before or during cooking. Efforts are being made to encourage threshing on jute or palmyrah-leaf mats, and the construction of permanent brick and cement communal threshing floors is advocated.

Manuring.—The application of manures to rice-fields is the exception

rather than the rule, although green-manuring is fairly extensively practised by Sinhalese cultivators in the Kandian districts, and by the Tamils in the extreme north of the Island. Green-manure crops, like *Crotalaria juncea*, are not grown for the purpose of green-manuring. Among the trees whose leaves are used are *Azadirachta indica*, *Cerbera odollam*, *Borassus flabellifer*, *Erythrina lithosperma*, and *Gliricidia sepium*. Wild Sunflower (*Tithonia diversifolia*), which grows luxuriantly and is found wild in the mid-country, makes an excellent green-manure and its use is extending. The effects of green-manuring on yield have been investigated by Haigh and Joachim [6] and Lord [8, 9], and the chemical changes in the soil by Joachim and Kandiah [7]. It was found that the green material gave its maximum effect if applied under anaerobic conditions (i.e. after the soil had been flooded) and within a few days of broadcasting or transplanting. Applications of 5 tons per acre gave increased yields of 30 and 29½ bushels. An application of 1 ton per acre is more likely to be used. In two experiments in different years this dressing produced increased yields of 12½ and 15 bu. per acre. Farmyard manure is seldom used, is not available in large amounts, and its quantitative effect has not been studied. Its use on rice-fields is being encouraged. The effect of artificial manures on the yield of rice has been studied by Lord [8, 10, 11, 12] and Haigh and Joachim [5, 6]. The effect of manures on the composition of the paddy crop has been investigated by Joachim, Kandiah, and Pandittesekere [14].

Generally, it has been found that phosphoric acid is the limiting factor in Ceylon soils, and that the rice crop responds both to phosphoric acid and to nitrogen in the form of sulphate of ammonia or ammonium phosphate. Excluding the results of manurial trials in the Eastern Province, an examination of the others shows that an application of 1 cwt. of ordinary superphosphate or of bone-meal may be expected to give on an average an increase of from 10 to 15 bu. with a normal crop, and a residual effect of about half that amount. Sulphate of ammonia alone has not given profitable increases, but from dressings of 93–104 lb. per acre of both wide and narrow ratio Ammophos, increases varying from 10 to 25 bu. per acre were obtained. There is evidence to show that the wide ratio ammonium phosphate was more effective than the narrow. There was some residual effect. Recent experiments in the Eastern Province [12] have shown that at three widely separated centres there was at two centres no response, and at one little and non-significant response, to phosphoric acid. Three- and four-months' rices were grown and 1 cwt. of concentrated superphosphate (42 per cent. P_2O_5) was applied per acre. The experiments, which were identical at the three centres, included also applications of 1 cwt. per acre of Nicifos (22/18) and Ammophos (13/46). At two centres Nicifos gave significant increases of respectively 11·3 bu.[1] per acre (4-months' rice) and 9·3 bu. (3-months rice). The response to Ammophos was slightly less. At the third centre the increase due to Nicifos was 10·8 bu. per acre, but the experiment was just not statistically significant. It would appear, therefore, that in the soils of the Eastern Province (and perhaps in other soils in the Island) nitrogen

[1] Bushels of 45 lb.

is the limiting factor. Experiments have already been laid down to determine this. For the present it may definitely be said that the application of 1 cwt. per acre of one of the ammonium phosphates will pay when the price of paddy (rice in the husk) is not less than Rs. 1·50 per bu. In those areas where rice responds to phosphoric acid alone, manuring is profitable even with a price of Rs. 1 per bu. There is, however, little likelihood of artificial fertilizers being used on a large scale unless the price of paddy rises to somewhere near Rs. 2 per bu.

Generally, manurial experiments are carried out in small bunded plots with each replication complete within one field. It has been shown [13] that if a replication extends over two or more fields, the standard error may be largely increased. It has been noticed that where small bunded plots are used, particularly in places where drainage is difficult, the levels of the plots may vary. If heavy rain falls soon after sowing, there may be standing water on some plots and not on others. Standing water at this stage may retard growth, or even destroy the plant, perhaps by burying the seed, with the tiny plumule and radicle, under fine mud. Two manurial experiments carried out by the writer in bunded plots were spoiled by rain soon after sowing. Recently, plots have been used without bunds but with a 3-foot space between plots in the middle of which a shallow drain is constructed. This method avoids or reduces errors through differences of level and, judged by the magnitude of the response to fertilizer, there is little if any wash from one plot to another. The space between the plots is sown with rice. Owing to the small size of the fields in Ceylon, experimental plots must necessarily be small if (as is so desirable) a replication is to be laid down in one field. Plots of 1/80 acre, of which an inner area of 1/100 acre is harvested, replicated from four to six times give sufficiently small experimental errors.

Irrigation-water.—No data have yet been obtained on the optimum amount of water necessary for paddy. Generally the Irrigation Department allows 6 acre-feet for a dry-season crop of from 3 to 4 months. Although a fair amount of this water is lost in the channel by percolation, it is ample for a good crop. In parts of the Island it is the custom to allow irrigated fields to dry out after sowing to such an extent that cracks appear in the soil, in the belief that the aeration thus provided is beneficial at this stage. Two pot experiments were carried out to ascertain if drying out had any effect on yield. Three treatments were given: (*a*) periodic drying as practised by some cultivators, (*b*) continual submergence from ten days after transplanting until two weeks before harvesting, and (*c*) a combination of (*a*) and (*b*). In the first experiment no significant differences were obtained, but a second experiment in which the treatments were replicated eight times and which satisfied the requirements of the Z test gave the following comparative yields: periodic drying 100, continual submergence 131, and a combination of the two treatments 106. Continual submergence from an early stage in the growth of the plants not only gives increased yields but reduces weed-growth, and prevents any serious damage from the Swarming Caterpillar (*Spodoptera mauritia*), which is found chiefly in those areas where drying out of the soil is practised. The depth to which plants are submerged varies from

3 to over 12 in., depending on the height of the bunds (many are made too low), the amount of water available, and the presence or absence of drainage facilities. A depth of 6 in. is considered desirable.

Cost of cultivation.—Almost all the rice in Ceylon is grown either by small owner-cultivators or, more generally, by tenants on a share system. The share system of tenancy is not conducive to good cultivation as the tenant knows that he will only get half of any increased yield due to manuring, transplanting, or better tillage. The share system, however, appears to be unavoidable; a landlord will not consider cultivating by means of hired labourers on daily pay. In the share system of tenancy the tenant is financed by the landlord. Owing to the different systems of share-tenancy and the numerous loans which are made, generally in kind at 50 per cent. interest, no reliable figures of cost of cultivation under share-tenancy conditions are available.

The cost of cultivating with hired labour, using mould-board ploughs and Burmese harrows, has been recorded at two paddy-seed stations in the Eastern Province. Although these costs are undoubtedly somewhat greater than the cost of cultivating under a share-tenancy the figures may be of interest.

TABLE 2. *Cost of Rice Cultivation per Acre*

Operation	Station			
	Illupadichchenai		*Sengapadi*	
	Rs.	*cents.*[1]	*Rs.*	*cents.*
Repairing bunds	0	90	1	88
Ploughing and harrowing	8	80	7	86
Levelling	..		2 (Levelling and Sowing)	62
Sowing and making drains	0	40[2]		
Reaping	2	60	1	88
Carrying sheaves and stacking	1	95	1	52
Threshing	5	46	4 (Threshing and Winnowing)	90
Winnowing	1	92		
Fencing	1	99	1	00
Watching and Irrigating	7	39	9	20
Water Rate	1	30	0	50
Seed Paddy, 2 bu. at Rs. 1·50	3	00	3	00
Total	35	71	34	36
Yield per acre in bu. of 45 lb.	30		37	
Wages, men, per day	0	60[3]	0	50
Plough-bulls per pair per day	0	75	..	
Plough-buffaloes or bulls per pair per day	..		1	00

[1] Rs. 1 equal 1*s.* 6*d.* [2] Dry sowing of ungerminated seed.
[3] 75 cents at harvest.

The rent of land varies largely, but a general rent is between Rs. 7 and Rs. 15 per acre; the price of unhusked rice for the past two years has varied between Rs. 1 and Rs. 1·50 per bu. At present a movement is on foot to increase the price of rice, either by increasing the existing moderate import duty, or by a system of quotas.

Yields.—It has already been stated that the official estimate of the

yield of rice[1] is 14 bu. per acre, or less than half the yield in India, where conditions are not greatly dissimilar. Although the estimate of 14 bu. is too low, there is little doubt that average yields in Ceylon are really lower than in India. This may be ascribed to the following reasons: (i) A proportionately greater area of short-aged rices is grown in Ceylon and, other things being equal, the longer the age the higher the yield. (ii) Ceylon figures for area include twice over land that is cropped twice a year, and it is believed there is more double cropping in Ceylon than in India. Double-cropped land per crop yields less than once-cropped land. (iii) Appreciable areas of land in Ceylon fail to mature a crop, or a normal crop, owing to failure of rains or shortage of irrigation water. (iv) Transplanting is widely practised in India. In Ceylon it is the exception, and it is doubtful if transplanting is profitable with short-aged varieties. A more reliable estimate of yields is contained in the report of the Director of Irrigation, and in 1931 the yield of over 161,000 acres of rice under major works is given as 21·2 bu. per acre. Of these figures the area is based on measurement, the yield on estimates and not on crop cuttings. Estimates of yields, which are made after consultation with cultivators, are invariably on the low side as both landlords and tenants are reluctant to divulge the true yields. Excluding areas which fail to mature a normal crop due to lack of water, the yield of rice in Ceylon is probably between 20 and 30 bu. per acre. The following yields, using 3–4-months' pedigree selections, and with good cultivation but no manuring, have been obtained recently in the Eastern Province: 354 bu. from 10 acres in 1932–3 (35·4 bu. per acre), 297 bu. from 10 acres in 1933–4 (29·7 bu. per acre), 438 bu. from 12½ acres in 1933 (35 bu. per acre), 465 bu. from the same area in 1934 (37 bu. per acre). In 1934, at the paddy-seed station of Tamblagam, which is situated on good soil, the following high yields were obtained, without manuring, from a broadcasted crop: 3-months' rice, 53·2 bu. per acre; 3¾-months' rice, 71·3 bu. per acre. There is evidence from all over Ceylon that with good cultivation yields of 30 bu. per acre can be obtained without difficulty.

Pests, diseases, weeds.—Insects are much more important than fungus diseases, but even the damage caused by insects is not extensive. In some areas, where bunds are low and irrigation-water is not issued at the right time, serious damage may be caused by the Swarming Caterpillar (*Spodoptera mauritia*). The Paddy Fly (*Leptocorisa varicornis*) is universal, but the damage caused is noticed only in small patches, which mature before or after the bulk of the crop, or in small areas of rice-land surrounded by extensive tracts of jungle and grassland. It is possible that the damage by Paddy Fly is more than is realized. The stem-borer (*Schoenobius bipunctifer*) is also universal, but is not found in large numbers, and the damage caused is slight. Two pests of stored rice are the Paddy Moth (*Sitotroga cereallela*) and the Paddy Weevil (*Calandra oryzae*). The former attacks rice in the husk only. At Peradeniya the germination of rice in four months was reduced by 15 per cent. due to damage by

[1] Except where otherwise stated, 'rice' in this paper means 'rice in the husk' or 'paddy'.

these two insects. Fungus diseases like *Rhizoctonia solani* and *Sclerotium oryzae* [15] cause, on the whole, little damage, but under certain conditions the latter may become serious. At Peradeniya, for example, the young plants of a foreign rice were almost completely destroyed by this disease.

In the sparsely populated parts of Ceylon the far too numerous wild elephants and pig do considerable damage to the rice crop, and elephants occasionally kill cultivators watching their fields at night. Land crabs (*Paratelphusa oziotelphusa hydrodromus*) are found in large numbers in paddy fields in Ceylon. They eat young plants and the seed-rate is heavy to make up for this loss. Crabs live in burrows in the bunds and the most serious damage occurs in the terraced cultivation of hill-sides, where the burrows may form channels for the water impounded in the field. Not only is water lost, but the passage of the water weakens and in time destroys portions of the bund. Crabs can be trapped in earthenware pots whose diameter in the middle is much larger than the diameter of the mouth. The most effective way of catching them is by boys who can catch from 100 to 200 per day. On an area of about 5 acres at Peradeniya 55,925 crabs were caught in the course of one year. Except where breeding or fine experimental work is in progress, it is not considered economic to attempt to reduce the number of crabs by traps or by boys.

Fimbristylis miliacea and several species of *Cyperus* are very common weeds on rice-fields and at times are present in such abundance that yields are greatly reduced. *Panicum crus-galli* is also common but not so serious. Good preliminary cultivation, together with shallow submergence of the fields as soon as the plants are about 3 in. high, increasing to 6 in. submergence as soon as the plants are about 9 in. high, will check or prevent weed-growth. Where water is not available for submergence in the early stages of the growth of the plant, weeding is advisable, but is seldom done outside the Kandian districts.

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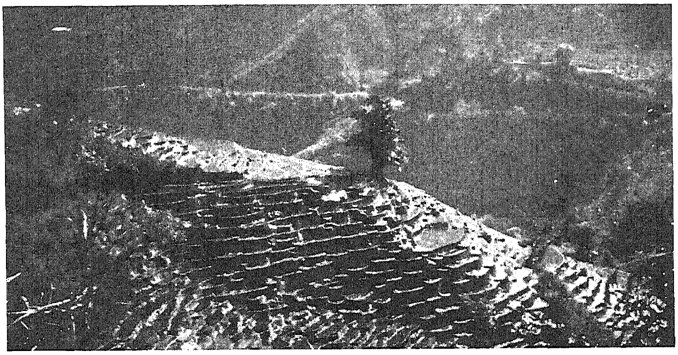

TERRACED RICE-FIELDS

A BURMESE HARROW

HARVESTING RICE

COMPARATIVE TRIALS OF CALCIUM CYANAMIDE AND OTHER NITROGENOUS FERTILIZERS ON ARABLE CROPS

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In a series of laboratory and pot-culture experiments with calcium cyanamide [1, 2, 3, 4] briefly reviewed in an earlier paper in this *Journal* [5], it was shown that whereas cyanamide was decomposed to ammonia within a few days in normal soils, the nitrification of the ammonia in pot-culture experiments might suffer a delay of several days or weeks.

On the assumption that the rate and extent of nitrification measure the availability of fertilizer nitrogen for plants, many earlier workers concluded from laboratory experiments that cyanamide would be a slowly acting or inefficient nitrogenous fertilizer on soils in which it delayed nitrification. It was shown [4], however, that in pot cultures on barley and mustard in a Millstone Grit soil, a prolonged delay in nitrification and accumulation of ammonia from cyanamide led to more rapid and better growth than was obtained from equivalent amounts of sulphate of ammonia. It was suggested that ammonia, when distributed uniformly throughout the soil, provides a more rapidly available source of nitrogen to plants than an equivalent amount of nitrate.

Uniform distribution of ammonia cannot be obtained from field applications of sulphate of ammonia, for the ammonium ion is held by the soil colloids in an immobile form. Nitrate, on the other hand, is rapidly distributed by the movement of soil water and by diffusion, and its well-known rapidity of action undoubtedly depends on the speed with which it reaches the roots of plants.

Apart from possible toxic effects, the essential differences in the behaviour of the common nitrogenous fertilizers in the field must depend primarily on their rates of production and distribution of ammonia and nitrate throughout the soil. The effects of different rates of diffusion and leaching cannot be deduced with any confidence from soils studied under laboratory and pot-culture conditions. Field experiments must provide the ultimate test of the behaviour of a fertilizer.

A series of field experiments was therefore conducted over a period of years and at many centres throughout England, to compare the fertilizer value of calcium cyanamide against those of other common nitrogenous fertilizers. Most of the experiments were on spring crops which received their nitrogenous dressings shortly before the seeds were sown. A few experiments were also made at Rothamsted on autumn-sown cereals to test the possibility that inhibition of nitrification might be advantageous through minimizing winter losses by leaching. This paper summarizes the results and conclusions from a series of field experiments testing equivalent amounts of cyanamide, sulphate of ammonia, and other nitrogenous fertilizers under a variety of agricultural conditions at Rothamsted, Woburn, and a number of other centres during the seasons 1927 to 1932.

All of the experiments were designed so as to be capable of statistical examination, and only those differences in yield which are statistically significant are quoted in the text. Several of the experiments were of the complex pattern in which two or more groups of treatments were tested together in all combinations with the object of providing (1) a broad basis for the over-all comparisons, and (2) the possibility of detecting interactions between treatments. In most of the cereal experiments the nitrogen percentages on dry grain and straw were determined on samples from each plot. The full agricultural details and the yields are given in the Annual Reports of the Rothamsted Experimental Station.

FIELD EXPERIMENTS ON SPRING CROPS

Table 1 summarizes the yields and the nitrogen-contents of the grain and straw in four experiments on barley conducted at Rothamsted. The first three included both single and double dressings of the nitrogenous fertilizers; those of 1927 and 1928 provided directly comparable figures for each different rate of dressing, but in 1928 the single and double dressings were tested in separate, but adjacent experiments. Superphosphate was tested in conjunction with the nitrogenous dressings in the first three seasons, and sulphate of potash in 1929, but, as there were no significant interactions between the nitrogenous and the mineral manures, the results presented here refer only to the means of the various mineral dressings. Samples of the barley grain were examined as a part of the Institute of Brewing Research Scheme, and the full analytical data have already been published in an appendix to the 'Investigations on Barley—Report on the Ten Years of Experiments' [6].

The grain yields on unmanured plots were low in the first two years and high in the last two years, but in every year there was a highly significant response to each one of the nitrogenous dressings. The results therefore provide a good opportunity for comparing the effects of the different forms of nitrogen.

The summary of significant results in Table 1 shows that cyanamide never gave definitely better results than any of the other nitrogenous fertilizers used.

For single dressings, i.e. 1 cwt. of cyanamide or 0·2 cwt. nitrogen per acre, there was no significant difference in the yield of grain from the different forms in any year. In straw yield, cyanamide fell below sulphate of ammonia once in four trials, and below nitrate of soda in the only trial made.

With double dressings differences occurred more frequently. Thus, in grain yield cyanamide fell below nitrate of soda in both tests made, below muriate of ammonia in two tests out of four, below urea in one test out of three, and below sulphate of ammonia in one test out of four. In straw yield cyanamide never differed significantly from sulphate of ammonia, but it fell below each of the other fertilizers in one or other of the experiments.

Except in 1928 the nitrogen percentages on the dry grain were down to the level usual for malting barley. The single dressings of nitrogenous

fertilizer increased the nitrogen percentage of the grain only in the season 1928, when all nitrogen percentages were very high. All the double dressings increased the nitrogen percentage in the grain in 1927 and 1928. Nitrate of soda, but not the other fertilizers, increased the nitrogen percentage in the two years in which it was tested, 1929 and 1930. Earlier Rothamsted results showed that moderate nitrogenous dressings (1 cwt. sulphate of ammonia per acre) could be used to increase yield without incurring the risk of impairing the malting quality of the grain or of appreciably increasing the nitrogen-content of the grain. These results confirm the earlier findings and show, in addition, that other fertilizers behave as sulphate of ammonia. Heavier dressings, especially of nitrate of soda, may, however, give more nitrogenous grain.

The nitrogen-contents of the straw were high in 1927 and 1928 and low in 1929 and 1930. None of the fertilizers significantly increased the nitrogen percentage of the straw; indeed, in two seasons the straw grown without added nitrogen had a higher nitrogen percentage than the average of the straws grown with nitrogenous fertilizers.

Although the analysis of samples from the individual plots is necessary where it is desired to establish the significance of effects on the composition of crop, such detailed work is not necessary to determine the total nitrogen-content of the crop and the percentage recovery of the added nitrogen. The effects of treatment and the differences between replicates are so much smaller, relative to the mean, for nitrogen percentages than for yield that suitably taken samples could safely be bulked before analysis. In these experiments the nitrogen recovery varied from about nil to one-half. The differences between fertilizers were small by comparison with the effects of season and soil irregularity. In general, nitrate of soda gave higher recoveries than the other fertilizers.

It may be noted that in 1930 cyanamide gave significant increases in yields of grain and straw without increasing the total nitrogen-content of the crop. The paradox that a crop responded to a nutrient which it did not appear to absorb is an extreme illustration of an effect observed in the pot-culture experiments discussed in an earlier paper [4]. There, it was shown that during plant-growth the total amount of nitrogen present in the plant and in inorganic forms in the soil remained constant when a nitrogenous fertilizer had been applied, but increased slowly in soils without added nitrogen. In the field experiments barley could use the early supplies of available nitrogen from the fertilizers for increased carbohydrate synthesis. When no nitrogenous fertilizer was added, the extra available nitrogen produced from the soil organic matter at a late stage of growth would tend to maintain vegetative growth and give higher percentages of nitrogen in dry matter, especially in the straw. In the 1930 field experiment with barley, the extra early nitrogen from cyanamide, which was utilized for increasing the yield, was apparently equal in amount to the extra late nitrogen from the soil of the plots without nitrogenous fertilizers.

The results of the Rothamsted barley experiments as a whole show no consistent differences between the fertilizers, though cyanamide

TABLE 1. *Rothamsted Barley Experiments, 1927 to 1930*

Year	*Form of experiment*	*Reference in Rothamsted Report*	*Reference in Barley Report* (6)	*Mean percentage dry-matter content of crops*	
				Grain	*Straw*
1927	4 blocks of 12 plots	1927–8, p. 131	p. 366	81·3	71·0
1928	8 blocks of 12 plots	1927–8, p. 133	p. 368	80·1	72·4
1929	One 5 × 5 Latin square for 4 single dressings and no nitrogen, and one 5 × 5 Latin square for 5 double dressings	1929, p. 89	p. 372	85·8	88·2
1930	5 × 5 Latin square	1930, p. 134	p. 381	83·9	80·5

Treatments and Symbols

O No added nitrogen
Cy Calcium cyanamide
S Sulphate of ammonia
M Muriate of ammonia (technical ammonium chloride)
U Urea
N Nitrate of soda
S.E. Standard error

Year	*Nitrogen applied cwt. N per acre*	Grain O	Grain Cy	Grain S	Grain M	Grain U	Grain N	Grain S.E.	Straw O	Straw Cy	Straw S	Straw M	Straw U	Straw N	Straw S.E.
	Yields in cwt. per acre														
1927	0·21	11·8	18·0	17·0	18·1	16·4	..	0·85	15·4	20·8	20·4	20·0	20·0	..	1·06
	0·41		17·9	18·9	23·5	21·9	..			20·7	22·2	27·0	24·3	..	
1928	0·21	14·3	16·7	17·8	17·3	17·5	..	0·59	24·4	28·8	32·1	31·3	31·3	..	0·94
	0·41		18·8	17·3	18·7	17·9	..			33·8	34·5	36·2	32·8	..	
1929	0·20	20·1	23·6	23·1	23·6	..	25·6	0·88	20·3	23·5	23·9	23·1	..	26·7	1·06
	0·40	..	26·3	25·2	26·2	25·4	27·8	0·44	..	25·6	24·9	25·5	24·0	27·4	0·71
1930	0·40	20·5	22·3	24·2	24·4	..	25·2	0·47	23·4	26·1	26·6	26·8	..	28·6	0·71
	Nitrogen percentage of dry matter														
1927	0·21	1·46	1·52	1·45	1·46	1·48	..	0·018	0·90	0·75	0·85	0·80	0·78	..	0·057
	0·41		2·01	1·49	1·51	1·52	..			0·83	0·83	0·84	0·74	..	
1928	0·21	1·93	2·11	2·05	1·99	2·02	..	0·022	0·78	0·75	0·77	0·70	0·79	..	0·031
	0·41		1·48	2·17	2·08	2·13	..			0·77	0·88	0·84	0·83	..	
1929	0·20	1·46	1·48	1·46	1·47	..	1·47	0·015	0·35	0·34	0·34	0·35	..	0·34	0·008
	0·40	..	1·50	1·48	1·49	1·49	1·54	0·021	..	0·33	0·34	0·35	0·32	0·35	0·010
1930	0·40	1·49	1·50	1·54	1·53	..	1·59	0·014	0·61	0·46	0·49	0·45	..	0·47	0·019

Percentage Recovery in Crop of Added Nitrogen

Year	Nitrogen applied cwt. N per acre	In Grain					In Grain + Straw				
		Cy	S	M	U	N	Cy	S	M	U	N
1927	0·21	37	29	36	28	..	45	41	44	35	..
	0·41	20	22	36	32	..	25	29	52	39	..
1928	0·21	23	34	27	30	..	32	53	36	49	
	0·41	23	20	22	21	..	35	39	42	35	
1929	0·20	24	18	23	..	35	14	12	14	..	22
1930	0·40	6	14	14	..	20	1	12	10	..	16

Summary of Significant Differences between Fertilizers ($P < 0·05$):

	Grain		Straw
Yield:			
1927	2M, 2U>2Cy; 2M, 2U>2S.		2M, 2U>2Cy; 2M>2S
1928	..	..	1S>1Cy; 2M>2U ..
1929	2N>2Cy;	2N>2S, 2M, 2U.	1N>1Cy; 1N>1S, 1M; 2N>2U, 2S
1930	2N, 2S, 2M>2Cy;	..	2N>2Cy; ..
Nitrogen percentage:			
1928	..	2S>2M.	2S>2Cy
1929	..	..	..
1930	2N>2Cy;	2N>2S, 2M.	..
1931	..	..	..

Weighted Mean Yields averaged for 4 Seasons

	No nitrogen	Calcium cyanamide	Sulphate of ammonia	Muriate of ammonia
Yield of grain, cwt. per acre	16·7	20·9	21·1	22·4
Yield of straw, cwt. per acre	20·9	26·0	26·6	27·7
Nitrogen per cent. of dry grain	1·58	1·64	1·66	1·64
Nitrogen per cent. of dry straw	0·66	0·59	0·63	0·60
Percentage recovery of added nitrogen in grain	..	18·5	19·2	23·6
Percentage recovery of added nitrogen in grain+straw	..	22·3	26·5	31·5

occasionally fell below one or other of the fertilizers with which it was compared. The mean yields for the four years, weighted to allow for the rates of application, show little difference between sulphate of ammonia and cyanamide; muriate of ammonia was slightly superior to both.

Attention must, however, be directed to one factor which may have operated to the detriment of cyanamide in these experiments and in many other comparisons recorded in the literature. Under the conditions of the English spring, it is difficult to obtain the desirable interval between applying cyanamide and sowing the barley crop in experimental work, though the practical difficulties are less acute in commercial farming. When the soil was prepared, the plots marked out, and the cyanamide applied, the farm staff considered it unsafe to incur the risk of a change of weather by delaying the application of the other fertilizers and the sowing of the barley for a few days or a week. In 1930 an attempt was made to overcome this experimental difficulty by applying the cyanamide three days after the barley was sown. It is possible that the relatively poor effects of cyanamide in this season may have been due to an inadequate or delayed distribution of the nitrate produced or to an adverse effect on the seedlings. Direct measurements on the rate and extent of germination showed, however, no significant effect.

Barley Experiments at Other Centres

In 1930 and 1931 five experiments were made on typical barley soils in Lincolnshire, Kent, and Hampshire. Each plot of a 4×4 Latin square, on forms of nitrogen, was subdivided into quarters to test phosphate and potash effects, but there was no significant interaction between the forms of nitrogen and the mineral manuring. The results presented refer then only to the full plots. Three of the five experiments showed significant responses to one or more nitrogenous fertilizers in grain and all of them showed responses in straw. Cyanamide was significantly below nitrate of soda and sulphate of ammonia in both grain and straw, in one experiment, and below nitrate of soda in straw in one other. Nitrate of soda gave more nitrogenous grain and higher nitrogen recoveries than the other fertilizers. These results (Table 2) are thus in general agreement with the Rothamsted experiments.

Experiments on Root Crops

In five out of eight experiments on potatoes there were significant responses to one fertilizer or to the average of all. Cyanamide fell below sulphate of ammonia in one experiment at Woburn, but in the same experiment there was no difference between sulphate of ammonia and cyanamide when both were used in conjunction with a small amount of nitrate of soda.

In the five sugar-beet experiments roots responded significantly to nitrogenous fertilizers in four experiments, and tops in the four experiments where they were weighed. Cyanamide was significantly below nitrate of soda and sulphate of ammonia in yield of roots in one experiment, and below nitrate of soda in yield of tops in another (Table 3, p. 136).

TABLE 2. *Field Experiments on Barley at Other Centres, 1930 and 1931*

4×4 Latin-squares (with plots subdivided to test phosphate and potash effects). The yields given refer to full plots only. All nitrogenous fertilizers supplied 0·2 cwt. of N per acre.

Detailed yields are given in the Rothamsted Reports: 1930, pp. 158, 160; 1931, pp. 168, 170, 172.

Detailed analyses are given in the Barley Report: pp. 383–91, except for Sparsholt, 1931.

Year *Centre*	*None* O	*Cyanamide* Cy	*Sulph. of amm.* S	*Nitrate of soda* N	*Standard error*	*Significant differences*
Yield of grain, cwt. per acre.						
1930 Wellingore	10·3	15·6	16·4	16·4	0·58	N, S, Cy>O
1930 Sparsholt	13·0	13·5	13·8	15·2	0·61	N>O
1931 Wellingore	29·9	30·3	29·6	29·6	0·53	None
1931 Sparsholt	16·4	17·2	17·8	17·2	0·50	None
1931 Wye, Kent	20·4	21·9	23·5	24·5	0·50	N, S>Cy>O
Mean	18·0	19·7	20·2	20·6	..	
Yield of straw, cwt. per acre						
1930 Wellingore	11·5	17·6	19·2	19·0	0·62	N, S, Cy>O
1930 Sparsholt	12·6	13·3	13·3	15·3	0·52	N>S, Cy, O
1931 Wellingore	32·6	34·9	35·7	35·9	0·46	N, S, Cy>O
1931 Sparsholt	26·2	28·3	29·2	29·6	1·02	Nitrogen>O
1931 Wye	19·8	21·7	24·5	27·0	0·88	N, S>Cy, O
Mean	20·5	23·2	24·4	25·4	..	
Nitrogen, percentage of dry grain						
1930 Wellingore	1·44	1·42	1·40	1·51	0·008	N>O, Cy, S
1930 Sparsholt	1·64	1·62	1·57	1·62	0·020	..
1931 Wellingore	1·36	1·36	1·36	1·37	0·018	..
1931 Sparsholt	1·52	1·56	1·57	1·66	0·043	Nitrogen>O
1931 Wye	1·40	1·42	1·39	1·47	0·026	..
Mean	1·47	1·48	1·46	1·53	..	..
Percentage recovery of added nitrogen in grain						
1930 Wellingore	..	32	36	48	..	..
1930 Sparsholt	..	2	2	14	..	..
1931 Wellingore	..	2	−2	−1	..	..
1931 Sparsholt	..	8	13	16	..	..
1931 Wye	..	10	18	32	..	..
Mean	..	11	13	21	..	..

Summary of Field Experiments on Spring-sown Crops

There are many plausible methods of averaging the results of a group of miscellaneous agricultural experiments containing a common question. In the past the yields with one fertilizer were sometimes set as percentages of the yields with another and these percentages were averaged. Experiments with poor responses to both fertilizers thus pointed towards the equality of the fertilizers tested, though the equality was in fact produced through inefficiency. Sometimes the ratios of the increments due to fertilizers were averaged and small responses then received undue weight or required arbitrary exclusion. From a sufficient body of data the results might be weighted by the rates of the dressings, the magnitude of the general responses and the standard errors of the experiments and, in addition, grouped according to varying agricultural

TABLE 3. *Field Experiments on Root Crops, 1926–31*

All yields in tons per acre. Agricultural details and full yields are given in the Rothamsted Reports for the appropriate years.

Year	*Centre*	*Reference to Rothamsted Reports*	*Nitrogen added cwt. per acre*	*None* O	*Cyanamide* Cy	*Sulph. of ammonia* S	*Nitrate of soda* N	*Standard error*	*Significant differences*
	Potatoes								
1926	Woburn	(1927-8) 155	0.21	6.5	7.3	7.4	..	0.20	S, Cy>O
			0.42	..	7.8	7.9	..		
1927	Woburn	157	0.31	6.5	6.9	7.2	7.1[1]	0.25	Nitrogen>O
			0.62	..	6.7	6.4	6.9[1]		
1928	Woburn	158	0.31	11.9	12.7	14.1	..	0.33	S>Cy, O
			0.31	..	13.6[2]	13.8[2]	..		S, Cy>O
1930	Woburn	153	0.20	..	12.0[3]	11.2[3]	..	0.41	..
			0.20	..	12.1[4]	11.4[4]	..		..
1931	Welshpool	191	0.60	4.8	7.2	7.9	7.5	0.32	S, Cy, N>O
1931	Hull	191	0.60	7.9	7.7	9.4	8.5	0.48	..
1931	Burford	191	0.60	..	5.2	5.2	..	0.18	..
1931	Bakewell	192	0.60	6.6	8.0	8.3	8.4	0.20	N, S, Cy>O
	Sugar beet (R = roots, T = tops)								
1928	Colchester	173	0.54 R	6.1	6.8	7.4	7.5[5]	0.26	N, S>O
1929	Welshpool	122	0.60 R	11.6	13.8	13.5	12.8[6]	0.26	Cy, S>M>O
			T	16.5	19.1	21.1	20.3[6]	0.93	Nitrogen>O
1930	Welshpool	169	0.40 R	11.6	12.0	13.3	12.6	0.14	S>N>Cy>O
			T	17.1	18.8	21.9	20.5	0.27	S>N>Cy>O
1930	Wye	170	0.62 R	10.6	12.6	12.4	12.7	0.19	N, Cy, S>O
			T	11.9	16.2	15.4	18.2	0.40	N>Cy, S>O
1931	Wye	193	0.27 R	11.8	11.8	11.9	11.8	0.14	..
			T	12.9	14.1	13.6	14.9	0.45	N, Cy, S>O

1 Urea used instead of nitrate of soda.
2 One-third of the nitrogen given as nitrate of soda.
3 With basic slag.
4 With superphosphate.
5 0.36 cwt. N as cyanamide and 0.18 cwt. N as nitrate of soda.
6 Muriate of ammonia (M) used instead of nitrate of soda.

conditions. For the data presented here it is sufficient to average the yields for each crop from experiments in which either sulphate of ammonia or cyanamide, or both, gave a significant response in yield. This eliminates the unresponsive centres and also those with unduly high experimental errors. Table 4 gives the results of 15 such experiments arranged in four groups. In each of these groups it happens that there is one experiment in which sulphate of ammonia gave significantly higher yields than cyanamide.

TABLE 4. *Mean Yields of Experiments in which Cyanamide and/or Sulphate of Ammonia gave significant Crop-increases*

Crop	*Number of expts.*	*No nitrogen*	*Cyanamide*	*Sulph. of ammonia*	*Response to cyanamide as % of response to sulph. amm.*
Barley (Rothamsted), cwt. grain per acre	4	16·7	20·6	21·0	92
Barley (other centres), cwt. grain per acre	2	15·4	18·8	20·0	70
Potatoes, tons per acre	5	7·3	8·5	8·9	78
Sugar-beet, roots, tons per acre	4	10·0	11·3	11·6	79

In these experiments at responsive centres, the mean difference in yield between sulphate of ammonia and cyanamide varied only from 2 to 6 per cent. of the mean yield. It is obvious therefore that the relative value of the two fertilizers cannot be estimated with any appreciable accuracy from such a restricted number of experiments. The few significant differences established in individual experiments and the mean yields for each group of responsive centres show that cyanamide was, on the whole, less effective than sulphate of ammonia under the conditions represented by these experiments. It must, however, be remembered that all the experiments were for a single year, and therefore included very little of those secondary effects on soil reaction and weed flora which may become important when one fertilizer is used repeatedly on the same land. A rotation experiment to examine possible cumulative effects of this type has recently been begun at Rothamsted.

EXPERIMENTS ON AUTUMN-SOWN CEREALS AT ROTHAMSTED

Although the autumn application of nitrogenous fertilizers to winter cereals has not become a general practice in this country, it has been suggested that a slowly acting fertilizer might have certain advantages for this purpose. If the leaching of nitrates during the winter months is a serious factor in soil fertility, then it is possible that materials known to be toxic to the nitrifying organisms might reduce this loss. A series of field experiments on winter oats and wheat was carried out at Rothamsted in the years 1929 to 1932, with the object of securing information on the relative effects of autumn and spring dressings of cyanamide and

sulphate of ammonia under varying agricultural conditions. The results are not easy to interpret, but it must be remembered that the whole problem of manuring winter crops is necessarily much more complicated than that of spring-sown crops. In the latter the added nitrogen is made available shortly before the time when the crop makes its maximum demand. With the former there is a long quiescent period; extra available nitrogen in autumn may even be disadvantageous, either by rendering the crop more susceptible to frost damage, by the well-known effect of high nutrient contents in restricting root-growth, or by affecting the competition between weeds and crop. Finally, with heavy crops the beneficial effects of the nitrogenous fertilizers may be offset by increased losses through lodging.

Oats, 1928–9.—In the first experiment, sulphate of ammonia, cyanamide, and both of these fertilizers, were tested in autumn and in spring in such a way that each autumn treatment occurred with each spring treatment, making 16 in all. It is thus possible to test the average overall effect of each dressing and to look for interactions between autumn and spring dressings.

TABLE 5. *Winter Oats, Rothamsted, 1928–9*

(Details in Rothamsted Report, 1929, p. 93)

Three blocks of 16 plots testing all combinations of sulphate of ammonia (S) versus none, cyanamide (Cy) versus none, autumn versus spring applications. Each single dressing supplied 0·16 cwt. nitrogen per acre. Autumn dressings on September 14 (Cy) and September 24 (S). Spring dressings on March 18 (Cy) and 19 (S).

	Grain, cwt. per acre Spring dressings					*Straw, cwt. per acre Spring dressings*				
	None	S	Cy	S+Cy	Mean	None	S	Cy	S+Cy	Mean
Autumn dressings None	14·2	12·8	13·9	10·1	12·7	22·5	23·1	26·0	23·7	23·8
Autumn dressings S	14·1	11·8	13·9	10·5	12·5	23·8	25·9	27·3	25·1	25·5
Autumn dressings Cy	13·0	13·4	15·9	12·7	13·7	21·2	28·2	26·6	26·5	25·6
Autumn dressings S+Cy	13·6	13·4	12·8	14·1	13·5	24·9	28·5	26·6	28·7	27·2
Mean	13·7	12·8	14·1	11·8	13·1	23·1	26·4	26·6	26·0	25·5

Standard error of single values: 0·84 for grain; 1·16 for straw. Mean nitrogen percentage of dry matter: 1·73 for grain; 0·25 for straw.

In grain, the spring applications, especially of sulphate of ammonia, reduced the yields, except on plots which had received cyanamide in the autumn. In straw, each of the single dressings, whether in autumn or in spring, increased the yield, but there was no additional response to the double dressing at either season. The response of straw yield to spring sulphate of ammonia was greater on the plots which had received cyanamide in the autumn. This positive interaction between autumn cyanamide and spring ammonium sulphate in both grain and straw yields is not easy to interpret. The oats were unusually weedy, and it may have been that autumn cyanamide checked some of the weeds and enabled the oats to respond better to the spring sulphate of ammonia. Comparison of the yields by the sampling technique with the total yields for the full plots showed that discrepancies due to weeds in the straw were greater on the sulphate of ammonia plots than on the cyanamide plots [7].

The nitrogen percentages of the grain and the straw were determined for each plot, but there were no significant effects.

Winter Wheat, 1929–30.—Since dicyanodiamide is known [1, 2] to decompose slowly in the soil and to be toxic to nitrifying organisms, it might serve to reduce losses of nitrate by winter leaching. A direct test on the effects of an autumn dressing of dicyanodiamide (prepared by the method described in an earlier paper [8]) was combined with a comparison of autumn and spring dressings of cyanamide and sulphate of ammonia. In this experiment there were no plots without added nitrogen. Half the plots were grazed by sheep for a day in late spring. This treatment significantly reduced the grain and straw yields and increased the nitrogen percentages of the grain, without giving significant interactions with any of the other treatments. The differences in yield between

TABLE 6. *Winter Wheat, Rothamsted, 1929–30*

(Details in Rothamsted Report, 1930, p. 140)

Three blocks of 16 plots, each of 1-60th acre, on wheat sown on October 22, 1929, testing all combinations of autumn versus spring dressings, sulphate of ammonia (S) versus cyanamide (Cy) (each supplying 0·3 cwt. of nitrogen per acre), autumn dicyanodiamide (dicy. supplying 0·2 cwt. extra nitrogen per acre) versus no extra nitrogen, and grazing versus no grazing. Autumn dressings applied on October 15 (Cy and dicy.) and on October 22 (S). Spring dressings on April 15. Grazing by sheep on May 9.

	Yield of grain, cwt. per acre					*Yield of straw, cwt. per acre*				
	Autumn		*Spring*			*Autumn*		*Spring*		
	S	Cy	S	Cy	Mean	S	Cy	S	Cy	Mean
Without grazing	16·1	16·6	13·9	14·5	15·3	27·9	27·0	27·4	28·0	27·6
Without grazing + dicy.	15·2	17·6	16·2	15·5	16·1	28·4	30·0	31·3	27·4	29·3
With grazing	11·5	11·9	12·2	15·3	12·7	21·0	23·2	21·0	24·3	22·4
With grazing + dicy.	13·5	16·5	14·0	13·1	14·3	25·3	29·3	24·3	22·9	25·4
Mean	14·1	15·6	14·1	14·6	14·6	25·6	27·4	26·0	25·6	26·2

Standard errors for single values: grain, 1·75; straw, 1·73.

	Nitrogen, per cent. of dry grain					*Nitrogen, per cent. of dry straw*				
	Autumn		*Spring*			*Autumn*		*Spring*		
	S	Cy	S	Cy	Mean	S	Cy	S	Cy	Mean
Without grazing	1·93	1·90	1·90	1·89	1·90	0·34	0·33	0·30	0·33	0·32
Without grazing + dicy.	1·94	1·90	1·92	1·90	1·92	0·30	0·33	0·33	0·31	0·32
With grazing	2·00	1·97	1·95	1·91	1·96	0·39	0·36	0·34	0·30	0·35
With grazing + dicy.	2·03	1·88	1·98	1·94	1·96	0·35	0·30	0·35	0·35	0·34
Mean	1·98	1·91	1·94	1·91	1·93	0·34	0·33	0·33	0·34	0·33

Standard errors for single values: grain, 0·028; straw, 0·023.

autumn and spring dressings and between cyanamide and sulphate of ammonia were insignificant in grain and straw yield. Sulphate of ammonia gave slightly more nitrogenous grain. Dicyanodiamide increased the yields significantly for straw, but insignificantly for grain, and had no effect on the nitrogen percentages.

Wheat, 1930–1.—In order to test whether a steady supply of available

nitrogen had any advantage over the usual spring top-dressings, an experiment was made on winter wheat with constant total amounts of both sulphate of ammonia and cyanamide, divided between two spring dressings and between eight monthly dressings from October to May. Such divided dressings form the basis of the so-called Gilbertini system of manuring.

TABLE 7. *Winter Wheat, Rothamsted, 1930–1*

(Details in Rothamsted Report, 1931, p. 147)

5×5 Latin square to test dressings of sulphate of ammonia (S) and cyanamide (Cy) given in spring (March 20 and May 1), and divided between eight monthly dressings from end of October to end of May. Total application at the rate of 0·4 cwt. nitrogen per acre.

	No Nitrogen	*Divided dressings*		*Spring dressings*		S.E.
		S	Cy	S	Cy	
Grain, cwt. per acre .	15·6	20·2	15·7	18·9	20·5	0·69
Straw, cwt. per acre .	29·9	39·2	31·8	37·6	39·4	1·39

Sulphate of ammonia gave similar increases in yield in the spring and in the divided winter and spring dressings. Spring cyanamide was as effective as spring sulphate of ammonia, but the eight repeated dressings of cyanamide failed to increase the yield above the unmanured level. Apparently, the cumulative effects of repeated slight checks completely offset the benefit from the cyanamide nitrogen.

Wheat, 1931–2 (*large experiment*).—Wheat following a 4×4 Latin-square experiment on clover versus clover-ryegrass hay, each with bastard fallow versus a second hay-crop, was used to test autumn and spring dressings of sulphate of ammonia and cyanamide. Each of the 16 plots was divided into quarters for no nitrogen, autumn dressing, spring dressing, and both, and each of the quarters with fertilizer was halved again to compare cyanamide against sulphate of ammonia. This method of repeated splitting of plots did not prove satisfactory. It gave good accuracy for the over-all comparison of the two fertilizers in the 64 pairs of adjacent plots, but it allowed the possibility that certain effects of soil irregularity might appear in the results as highly complicated interactions between treatments. One of the highest-order interactions appeared statistically significant, but, as the main effects were small, no attempt will be made to state and interpret this isolated result. The results are given in Table 8 as the means and the differences for the two forms of nitrogen applied at different times.

The autumn dressings depressed the yields of grain but not of straw. The spring dressings had no effect on grain but increased the yield of straw. The nitrogenous fertilizers increased the nitrogen percentages in grain and straw. Cyanamide gave significantly higher grain yields than sulphate of ammonia, i.e. it caused smaller depressions.

The yields throughout the experiment were so high that little response to nitrogen was to be expected, but it is not clear why autumn sulphate of ammonia should reduce the yield of grain. The nitrogen recovered from the fertilizers remained in the straw.

TABLE 8. *Winter Wheat, Rothamsted, 1931–2*

(Details in Rothamsted Report, 1932, pp. 34, 142)

Sixteen plots divided into quarters for time of nitrogenous dressings and into eighths for sulphate of ammonia and cyanamide.

Each single dressing supplied 0·3 cwt. nitrogen per acre.

Autumn applications were made on October 29, 1931, and spring applications on March 24, 1932. Wheat was sown on October 31, 1931.

Time of application	*None*	*Autumn*	*Spring*	*Autumn and Spring*	*Standard error*
Means of nitrogenous dressings:					
Grain, cwt. per acre	27·6	26·3	27·8	25·8	0·56
Straw, cwt. per acre	48·7	49·6	54·2	52·2	1·00
Nitrogen, percentage of dry grain	1·93	2·01	1·98	2·05	0·007
Nitrogen, percentage of dry straw	0·49	0·60	0·58	0·67	0·023
Percentage recovery of added nitrogen in grain+straw.	..	15	25	15	..
Extra yield from cyanamide over that from sulphate of ammonia:					
Grain, cwt. per acre	..	+0·8	+1·2	+1·5	0·44
Straw, cwt. per acre	..	+0·7	−1·4	−0·3	0·62

Wheat, 1931–2 (*small experiment*).—A supplementary experiment was conducted in 1931–2 to obtain further evidence on two questions tested in the preceding years. No nitrogen, spring sulphate of ammonia and autumn cyanamide were taken as standard treatments against which to compare divided dressings of sulphate of ammonia (6 monthly dressings), and a mixture of dicyanodiamide and cyanamide, each supplying one-half of the standard amount of nitrogen. This comparison is more direct than that on dicyanodiamide in the 1929–30 experiment, for here it is compared against an equivalent amount of cyanamide. The mixture approximates to that which could readily be obtained in practice by mixing cyanamide with superphosphate [3].

The wheat yield on the untreated plots was only two-thirds of that in the large experiment on an adjoining field. Each nitrogenous dressing gave a large and highly significant increase in both grain and straw. The mixture of dicyanodiamide and cyanamide applied in autumn gave significantly higher yields of grain than any of the other three nitrogenous dressings. It gave significantly higher yields of straw than the autumn cyanamide or the spring sulphate. As in the 1930–31 experiment, there was no difference between a single spring dressing of sulphate of ammonia and the repeated divided dressings throughout winter and spring.

It will be noted that, although there was a high recovery of the added nitrogen, the nitrogen percentages in grain and straw were not appreciably affected by the fertilizer, except that spring sulphate of ammonia increased the nitrogen percentage of the straw. It is noteworthy that in an experiment with efficient utilization of the added nitrogen the dicyanodiamide-cyanamide mixture gave the best results.

TABLE 9. *Wheat, Rothamsted, 1931–2*

(Details in Rothamsted Report 1932, p. 147)

Comparison of sulphate of ammonia in spring (March 15) and in six monthly dressings from November 24 to April 16, against cyanamide applied in autumn (October 28, 1931) and a mixture of cyanamide and dicyanodiamide supplying equal amounts of nitrogen applied in autumn (October 28, 1931).

Each treatment supplied, in all, 0·3 cwt. nitrogen per acre.

Form of experiment, 5 × 5 Latin square.

Treatment	*Time*	*Grain cwt. per acre*	*Straw cwt. per acre*	N % *in dry grain*	N % *in dry straw*	*Percentage recovery of added nitrogen*	
						in grain	*in grain and straw*
No N	..	18·9	23·2	1·92	0·48	..	..
S. Amm.	Spring	23·4	30·6	1·91	0·56	21	37
S. Amm.	Divided	24·2	33·0	1·93	0·48	26	38
Cyanamide	Autumn	24·6	31·3	1·93	0·48	28	39
½N as Cyanamide + ½N as Dicyanodiamide	Autumn	26·6	34·9	1·89	0·47	35	49
Standard error		0·66	1·02	0·021	..	..	..

Summary of Results on Autumn-sown Crops

The winter cereal experiments at Rothamsted from 1929 to 1932 show no such simple and consistent picture as the spring barley experiments in the same fields. Barley invariably gave highly significant responses to the nitrogenous fertilizers, but winter wheat and oats sometimes failed to respond to added nitrogen or were even reduced in yield. In two experiments (oats 1929, and wheat 1930) there was no appreciable difference between the effects of autumn and spring dressings of nitrogen, and in two others (wheat 1931 and 1932) there was no advantage in a series of small, repeated winter and spring dressings of sulphate of ammonia over an equal total amount applied in spring. There was no clearly defined or consistent difference between sulphate of ammonia and cyanamide applied in single dressings either in autumn or spring. Twice sulphate of ammonia slightly depressed the grain yield and cyanamide had no effect. In the more normal experiments, where both forms of nitrogen increased the yield, there was no significant difference between the two forms.

Several of the experiments were planned on the assumption that considerable amounts of nitrate might be lost by winter leaching, and that cyanamide and dicyanodiamide might reduce this loss by checking nitrification. Since there was little difference between spring and autumn dressings, and between spring and repeated dressings in winter and spring, it would seem that loss of nitrate by winter leaching was not a major factor in determining crop yield in these experiments. It would also appear that an early supply of nitrogen offers no special advantage to the winter cereal, which is probably too small during the winter to utilize any appreciable fraction of the nitrogen added in autumn dressings. The results of these experiments are in harmony with the conclusion derived from subsequent experiments and from the results

of the Broadbalk experiments that, in the heavy Rothamsted soil, much of the nitrate leached out of the surface soil is stored in the subsoil and remains available to wheat, except when the spring and summer are very wet.

The distribution of nitrate throughout the subsoil must depend on the relationship of the rate of nitrification to the rainfall conditions. Since the Rothamsted soil nitrifies rapidly, the slight delay in nitrification from cyanamide was too small to have any appreciable effect, but that from the more stable dicyanodiamide was apparently sufficient to influence the distribution of nitrate in the following spring. The total effect on soil nitrate of the added fertilizers was probably quite small by comparison with the effects due to previous cropping and weather conditions.

Although autumn dressings may be as effective as spring dressings on winter cereals, there is sometimes little response to either; the spring top dressings provide the obvious practical advantage that in spring it is possible to decide from the state of the crop whether or not extra nitrogen is needed.

Much more field experimentation will be required before the nitrogenous manuring of winter crops grown in normal rotations can be treated with as much confidence as is possible for spring crops. Mixtures containing dicyanodiamide merit further examination under conditions where nitrification is slower or winter leaching more complete than in the Rothamsted soils.

Summary

1. In a series of 22 field trials at Rothamsted and other centres on spring crops—barley, potatoes, and sugar-beet—calcium cyanamide and ammonium sulphate gave similar yield increases in 11 of the 15 experiments in which there were significant responses to added nitrogen, and calcium cyanamide was less efficient than ammonium sulphate in the other four.

2. In five experiments at Rothamsted on winter cereals there was no clear difference between autumn and spring dressings of nitrogenous fertilizers or between calcium cyanamide and ammonium sulphate, except with repeated small applications during winter and spring, when calcium cyanamide was worse than sulphate of ammonia. Autumn dressings of dicyanodiamide, either alone or mixed with calcium cyanamide, gave good results on winter wheat.

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A COMPARISON OF THE FEEDING-VALUES OF GRASS ENSILED BY THE A.I.V.-PROCESS AND A RATION CONTAINING MANGOLDS AND HAY

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THIS trial was carried out at the Old Parsonage Farm of Dartington Hall, Ltd., Totnes, S. Devon, and forms one of a series of A.I.V.-fodder trials sponsored by Imperial Chemical Industries, Ltd.

On September 15 and 16, 1932, about 10 tons of grass aftermath were ensiled. The herbage was chiefly cocksfoot and timothy containing small proportions of clover, perennial rye-grass, and members of the *Poa* family. It was mature and inclined to be stemmy.

The silo was a circular wooden pit, 9 ft. 9 in. diameter and 5 ft. high, sunk into the ground 1 ft. 6 in. with the sides banked with earth. It was not possible to sink the silo further owing to springs and downhill drainage-water which might seep into the pit. A catchpit filled with stones was dug in the centre and from it tile drains were laid to the hedge in order to carry off effluent in the early stages of compression.

The weather was dry and dull with sunny intervals, and the grass when cut had a normal moisture-content of 21·07 per cent. It was forked into the silo and the acid (standard A.I.V.-solution, consisting of a mixture of hydrochloric and sulphuric acids of 2N strength) was sprayed on continuously with a semi-rotary pump, at the rate of 20 gallons per ton. Composite samples of grass were taken during the two days of filling. When the wooden silo was filled, an over-silo of the same diameter and 6 ft. 6 in. high was put on and charging was continued until it was full. The top layers were sprayed with 'Homesurma' to inhibit mould, and a layer of nitro-chalk bags was laid over them. On these were placed a 4-inch layer of wet sawdust, followed by a loose cover of flat wooden boards, more sawdust, and finally 3½ tons of rock. The drain-opening was stopped up temporarily with a piece of sacking, which was removed after four days. There was a free flow of dark brown liquid for two or three days, and the drain was again closed after this had ceased. Analytical figures are given below.

The fodder had sunk below the level of the upper section by September 29, and this was removed and the top of the silo banked over with earth.

On November 22 the silo was opened. There were slight traces of mould at the sides and the top inch-layer of fodder was blackened and unusable. The colour of the bulk was brownish-green and the smell sharp and pleasant. The quality was even throughout the mass. The pH value was 3·5. Samples were taken for analysis at intervals during the emptying of the silo and the results are given in Table 1 together with the analyses of the original grass.

It will be noted that the ratio of digestible protein to crude protein, both in the original grass and the resulting A.I.V.-fodder, is very low and that the percentage of fibre is high. This is due to the maturity of the grass. A slight loss of crude protein has taken place in the lower part of the silo, but the ratio of true and crude protein has not been altered. The percentage of fibre in the A.I.V.-fodder is slightly greater than in the grass. There has been a loss of ash constituents by drainage from the lower part of the silo, though the volume of effluent was not great.

TABLE I

	Grass			*A.I.V.-fodder*				
				Date of sampling				
	Sample 1	*Sample 2*	*Average*	*22/11/32*	*29/12/32*	*17/1/33*	*27/1/33*	*Average*
Crude protein	13·75	13·13	13·44	13·33	13·26	12·41	12·03	12·76
True protein (Stutzer)	10·31	10·94	10·63	10·97	9·31	11·16	10·00	10·36
Pepsin-HCl soluble protein	4·94	4·97	4·96	5·27	5·97	7·73	5·94	6·23
Ratio of true protein to crude protein	0·75	0·83	0·79	0·82	0·70	0·90	0·83	0·81
Ratio of digestible protein to crude protein	0·359	0·379	0·369	0·395	0·450	0·623	0·494	0·491
Ash	9·23	8·64	8·94	8·77	9·61	6·68	7·13	8·05
Phosphoric acid P_2O_5	0·63	0·59	0·61	0·53	0·58	0·39	0·35	0·46
Fibre	27·63	28·46	28·05	29·00	27·34	29·46	31·57	29·34
CaO	1·05	0·94	1·00	0·93	0·94	0·85	0·65	0·84
Ether extract	4·07	4·20	4·14	4·22	3·71	4·31	3·70	3·48
Moisture	77·08	80·77	78·93	79·58	81·86	86·21	81·75	82·34
Dry matter	22·92	19·23	21·07	20·45	18·14	13·79	18·25	17·66
pH	..	..	..	3·7	..	3·5	3·5	..

Virtanen [1] gives the following figures for protein in timothy grass and A.I.V.-fodder made from it:

	Dry matter	*Crude protein in D.M.* %	*True protein* %	*Ratio of true to crude protein*
Fresh grass	21·8	14·8	12·4	0·84
A.I.V.-fodder	21·0	14·6	12·0	0·82

These figures are the average of determinations on six samples of fresh grass and on twelve samples of silage, and are for pure strains of grass, whereas the timothy grass used here was in a mixed herbage. It will be seen that the moisture losses were less than in the experiment carried out here, and that the percentages of crude and true protein were considerably higher, which is no doubt accounted for by the stemminess of our grass. On the other hand the ratio of true to crude protein has been maintained at the same level.

A sample of effluent from the silo was taken and contained nitrogen equivalent to 0·41 per cent. crude protein, which agrees with the figure given by Virtanen [2] for clover silage. Watson [3] obtained a mean figure of 2·15 per cent. for the drainage liquid from young grass ensiled

in the ordinary manner, whereas Boyle and Ryan [4] found 1·6 per cent. Unfortunately, no measure of the amount of liquid flowing was obtained, so that the above figures are not strictly comparable and no estimation of the actual weights of protein lost can be made.

The claims which have been made on behalf of A.I.V.-fodder have to some extent been investigated under experimental conditions in Great Britain with regard both to the preservation of the essential food-value of the herbage and also the palatability and feeding qualities for dairy cattle. The present investigation was undertaken in order to extend the scope of a series of further experiments undertaken by Imperial Chemical Industries, Ltd. to practical farming conditions, with the maximum of scientific control.

It cannot be too strongly emphasized that in work upon dairy cattle it is impossible to obtain at one and the same time the strict statistical design which is scientifically desirable together with the practical farming conditions which alone can answer the question of the suitability of the method for application to the industry. Without the former the pure scientist will be unconvinced by the result, whilst the most carefully designed investigation which interferes with farming practice will fail to convince the working farmer.

A few points in the present feeding-trial are worthy of note as illustrating this point. The number of cows that could be used was limited to the herd of 55, which, as in most dairy herds, contained few full sisters, since the average number of lactations is rather under four, producing usually a total of two heifer calves. These sister cows would of course never be in the same lactation-period. If cows of a similar type which are half-sisters or unrelated are taken, it is extremely difficult to match two beasts at the same stage of lactation without keeping the cows dry for a period in order to get them into calf at the same time, a proceeding which would not be sound farming practice and which would undoubtedly vitiate the result in the eyes of the farmer. It would also affect the scientific accuracy of the experiment owing to the fact that little is known of the accumulation of reserves in a cow during a dry period. It is hardly necessary to point out that to match cows in different parts of the lactation-period is extremely unsound. Finally, in order to match pairs of cows, arrangements must be made long in advance—the difficulty of which is well known to any one familiar with the management of a dairy herd—in order that they may become accustomed to adjacent stalls. The drop in milk-yield following a complete reshuffling of the herd immediately prior to the experimental period would be sufficient to wreck the experiment completely.

It was decided, therefore, that to attempt to claim the use of similar pairs of cows in the experiment would be unjust and misleading. Instead, one row of the four in the cow-house, each containing 13–15 representative beasts, was selected by the farmer, and the feeding-trial was carried out with an experimental group on the period-reversal system in December, 1932, and January and February, 1933. The cows had been indoors since October and had not been moved from their stalls. The breed was pedigree Dairy South Devon.

The cows covered a wide range of ages and periods in lactation, and all had been in milk at least one month before the trial began. The cows were weighed before the first period and at the end of the first and each succeeding period. Milk records were kept for each cow weekly, and determinations of the butter-fat content of the milk were made. During the last week of each period butter was made from the bulked milk and the yellow colour determined by the Lovibond tintometer.

Before the feeding-trial began three cows, not included in the experimental group, were fed for several days with A.I.V.-fodder to ensure that no taint could be communicated to the milk.

Each period of the trial was five weeks long, and during the first and third periods each cow received a normal winter ration of hay, mangolds, and concentrates as fed to the whole herd. During the second period the mangolds and part of the hay were replaced by A.I.V.-fodder. Assuming a starch equivalent for the fodder of 10 per cent., and a protein equivalent of 1·04 per cent., 40 lb. of A.I.V.-fodder replaced 40 lb. roots and 5 lb. hay. Thus:

	Dry matter lb.	*Starch equivalent* lb.	*Digestible protein* lb.
40 lb. A.I.V.-fodder	8·00	4·0	0·42
40 lb. Mangolds	5·28	2·80	0·16
5 lb. Hay	4·30	1·55	0·23
Total	9·58	4·35	0·39

It was unfortunate that the low digestible-protein value made it impossible to replace any of the concentrates.

The maintenance ration for a South Devon dairy cow weighing about 1,400 lb. is 7·6 lb. starch equivalent, plus 0·86 lb. protein equivalent. Hay was fed in addition on a reducing scale according to the milk yield, from 25 lb. for a 2- and 3-gallon cow to 5 lb. for a 7-gallon cow. Typical rations for a 3-gallon cow are given in Table 2.

TABLE 2

	Periods 1 and 3				*Period 2*			
	Weight lb.	*D.M.* lb.	*S.E.* lb.	*P.E.* lb.	*Weight* lb.	*D.M.* lb.	*S.E.* lb.	*P.E.* lb.
Hay	21	18·0	6·51	0·97	16	14·0	4·96	0·73
Mangolds	40	5·3	2·80	0·16	..	..	..	..
A.I.V.-fodder	..	..	..	..	40	10·0	4·00	0·42
Concentrates	12	10·8	8·28	2·04	12	10·8	8·28	2·04
Total	73	34·1	17·59	3·17	68	34·8	17·24	3·19

The composition of the concentrates is as follows:

	lb.	*D.M.* lb.	*S.E.* lb.	*P.E.* lb.
Kernelin	2	1·80	1·60	0·40
Bran	2	1·74	0·84	0·20
Maize meal	3	2·61	2·43	0·20
Bean meal	2	1·71	1·32	0·40
Decorticated ground-nuts	2	1·79	1·46	0·82
Crushed oats	1	0·87	0·60	0·08
Total	12	10·52	8·25	2·10

Of this mixture is fed per gallon:

lb.	*D.M.* lb.	*S.E.* lb.	*P.E.* lb.
4	3·6	2·76	0·68

The younger cows took to the silage readily and ate with relish, but the older ones needed much persuasion and were never greatly interested. There was no scouring.

Milk yields were recorded weekly with the rest of the herd. Table 3 gives the calculated average weekly yields per cow and average rate of fall.

TABLE 3

Period	*Week*	*Average weekly yield in lb. per cow* *A.I.V.*	*Rest*	*Difference*	*Average rate of fall in lb. per cow per week* *A.I.V.*	*Rest*
Transition	1	233·4	177·7	55·7	..	..
I	2	221·4	173·9	47·5	−12·0	−3·8
	3	222·5	171·7	50·8	+1·1	−2·2
	4	211·7	162·6	39·1	−10·8	−9·1
	5	202·7	158·0	44·7	−9·0	−4·6
					Mean −7·7	Mean −4·9
Transition	6	179·0	143·7	25·3	−23·7	−14·3
II	7	183·7	149·3	34·4	+4·7	+5·6
	8	179·7	143·8	35·9	−4·0	−5·5
	9	182·0	136·8	45·2	+2·3	−7·0
	10	174·2	129·8	44·4	−7·8	−7·0
					Mean −1·2	Mean −3·5
Transition	11	168·8	125·7	43·1	−5·4	−4·1
III	12	165·2	123·9	41·3	−3·6	−1·8
	13	149·3	121·1	28·2	−15·9	−2·8
	14	149·6	118·3	31·3	+0·3	−2·8
	15	151·2	113·6	37·6	+1·6	−4·7
					Mean −4·4	Mean −3·0

These results are also given in graphical form, together with the mean temperature for the corresponding week (Fig. 1).

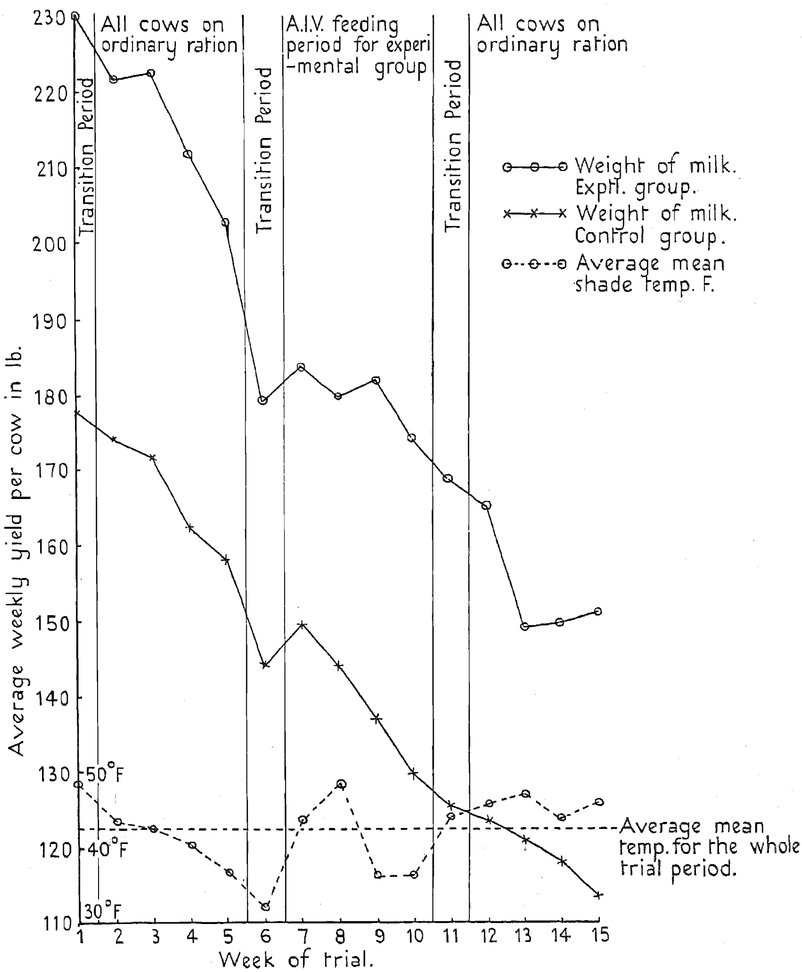

FIG. 1. Average weekly yield of milk per cow of cows fed on hay, mangolds, and concentrates, and of cows fed on a ration in which A.I.V. fodder partly replaced hay and mangolds. Average weekly shade temperatures during the trial.

It will be seen that there was a sudden decrease in the milk-yield on changing over to the A.I.V.-fodder. This was, no doubt, due to the unusual nature of the ration but the change also coincided with a sudden spell of very cold weather. During the actual period when A.I.V.-fodder was given the mean rate of fall was much less, and steadier, than during the first or the third period.

The decrease in milk-yield of the control group during the transition period was not as great as in the experimental group of cows. The cold spell evidently had a considerable share in the drop in yield of the experimental group, which was therefore only partly due to the change over to the A.I.V.-fodder. Further, the average rate of change during

weeks 7 and 8 was in the same direction over the whole herd and of the same order.

The total average yields per cow during the trial for each of the four-week periods is given in Table 4.

TABLE 4

Period	Total average yield (lb.)	
	A.I.V.-group	*Control-group*
I	858·3	666·2
II	719·6	536·1
III	615·3	470·5
Mean I and III	736·8	568·4
Difference from II	17·2	32·2
Equivalent to, per day	0·6	1·2

This estimated drop in yield during the A.I.V. feeding-period is 2·4 per cent. for the experimental group and 6 per cent. for the control group. It is not certain whether this is within the limits of experimental error and therefore no conclusion is drawn from it. It is unfortunate that the amount of silage made was insufficient for a longer feeding-trial, so that the transition periods could have been longer than a week.

Determinations of percentage butter-fat were made weekly. Table 5 shows the average yield of butter-fat per cow and the average fat-content of the milk for each of the three periods. It will be seen that there was a slight but not significant increase in the fat-content of the milk when the cows were fed on A.I.V.-fodder.

TABLE 5

	Average yield of butter-fat per cow lb.	*Average fat-content of milk* %
Period I	36·93	4·302
,, II	31·21	4·337
,, III	25·97	4·232
Average of periods I and III	31·45	4·267

Samples of butter were made from mixed milk of the group at the end of each feeding-period and the yellow colour was estimated by the Lovibond tintometer [5]. The yellow colour during the A.I.V.-fodder feeding-period was more than double that in either of the other two periods. The butter produced during these control periods was the typical colourless produce of winter months:

Period	*Lovibond yellow units*
I	4·0
II	8·4
III	2·8

The consistency of the butter was also improved.

It has been shown [6] that the intensity of the yellow colour of butter is closely correlated with the vitamin-A content for Shorthorn cows, and it is likely that this parallelism applies also to the South Devon breed.

Spectroscopic determinations of vitamin A, carotene, and xanthophyll were made at Liverpool by Prof. I. M. Heilbron [7] and showed that these values were proportional to the yellow colour of the butter.

The cows were weighed at the beginning of the trial and at the end of the feeding-period. Table 6 gives the mean weights per cow.

TABLE 6

	Pre-trial period	*End of period I*	*End of period II*	*End of period III*
	cwt. qr. lb.	cwt. qr. lb.	cwt. qr. lb.	cwt. qr. lb.
Average weight per cow	14 0 26	13 0 17	14 1 15	13 2 26

It will be seen that the average loss in weight of 1 cwt. per cow during period I was made up when A.I.V.-fodder was fed in period II, although the weight of dry matter in 40 lb. A.I.V.-fodder was 7 lb., as against $9\frac{1}{2}$ lb. dry matter in 40 lb. mangolds and 5 lb. hay. The digestible protein in the A.I.V.-fodder was only slightly greater than that of the mangolds and hay, and therefore the increase in weight in period II cannot be accounted for by any increase in weight of nutrient supplied.

It is suggested that that part of the fall in milk-yield, which could not be accounted for by the sudden cold spell during the transition period when the feeding of A.I.V.-fodder commenced, might have been prevented by a more gradual introduction of the fodder into the ration.

Conclusion.—The object of this paper is to answer the question: If A.I.V.-fodder is used to replace mangolds and part of the hay in a ration, what will be the effect on (1 *a*) the quantity, (1 *b*) the quality, of the milk, and (2) the cow?

Briefly the answers are:

(1 *a*) No change of agricultural significance.
(1 *b*) Butter-fat content hardly affected, colour and vitamin-A content much improved.
(2) No scouring or ill effects. Eaten with relish by younger cows. Live weight maintained.

It is not claimed that the fodder will have any startling effects on the condition or milk-yield of a herd, but that it may replace more expensive portions of a ration effectively, when used under normal farming conditions. It should, therefore, be of use to farmers as a means of conserving grass in difficult hay seasons, of making effective use of sudden flushes of grass or excess aftermath, of cutting out root-crops with their high labour costs, and of improving the quality and appearance of the milk, particularly during the winter months.

Summary

1. Mature aftermath grass was ensiled by the A.I.V.-process.

2. The analytical values for the fresh grass and the A.I.V.-fodder show that little change occurred in the content of protein, though the values for phosphoric acid and calcium are lower in the silage. No estimate of the losses can be made since the grass was not accurately weighed when filled in to the silo and the total weight of A.I.V.-fodder is not known.

3. A feeding-trial was carried out with South Devon dairy cows on the period-reversal system; 40 lb. A.I.V.-fodder replaced 40 lb. mangolds and 5 lb. hay.

4. The milk-yield during the A.I.V.-fodder feeding-period fell by 1·2 lb. per cow per week compared with values of 7·7 lb. and 4·4 lb. during the preceding and following control periods. There was a pronounced fall during the transition period when the cows were being brought on to the A.I.V.-ration. This was only partly due to the change of ration, since the milk-yield of the rest of the herd fell sharply at the same time, due to a severe spell of cold weather.

5. The average percentage butter-fat was slightly, but not significantly, higher during A.I.V.-feeding: 4·34 per cent. compared with an average of 4·27 per cent. before and after.

6. The colour of the butter-fat was more than doubled during A.I.V.-feeding.

7. The live weights of the cows fell during the control periods and rose to slightly above the initial weights during A.I.V.-feeding.

My thanks are due to Messrs. Imperial Chemical Industries, Ltd., Agricultural Research Station, Jealott's Hill, for the Lovibond-tintometer determinations of the yellow colour of the butter, and for their co-operation in the conduct of this experiment; and to Mr. C. F. Nielsen, Manager of the Old Parsonage Farm, Dartington, for his assistance and co-operation in the feeding-trial.

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THE GRASSLANDS OF KENYA

I. AREAS OF HIGH MOISTURE AND LOW TEMPERATURE

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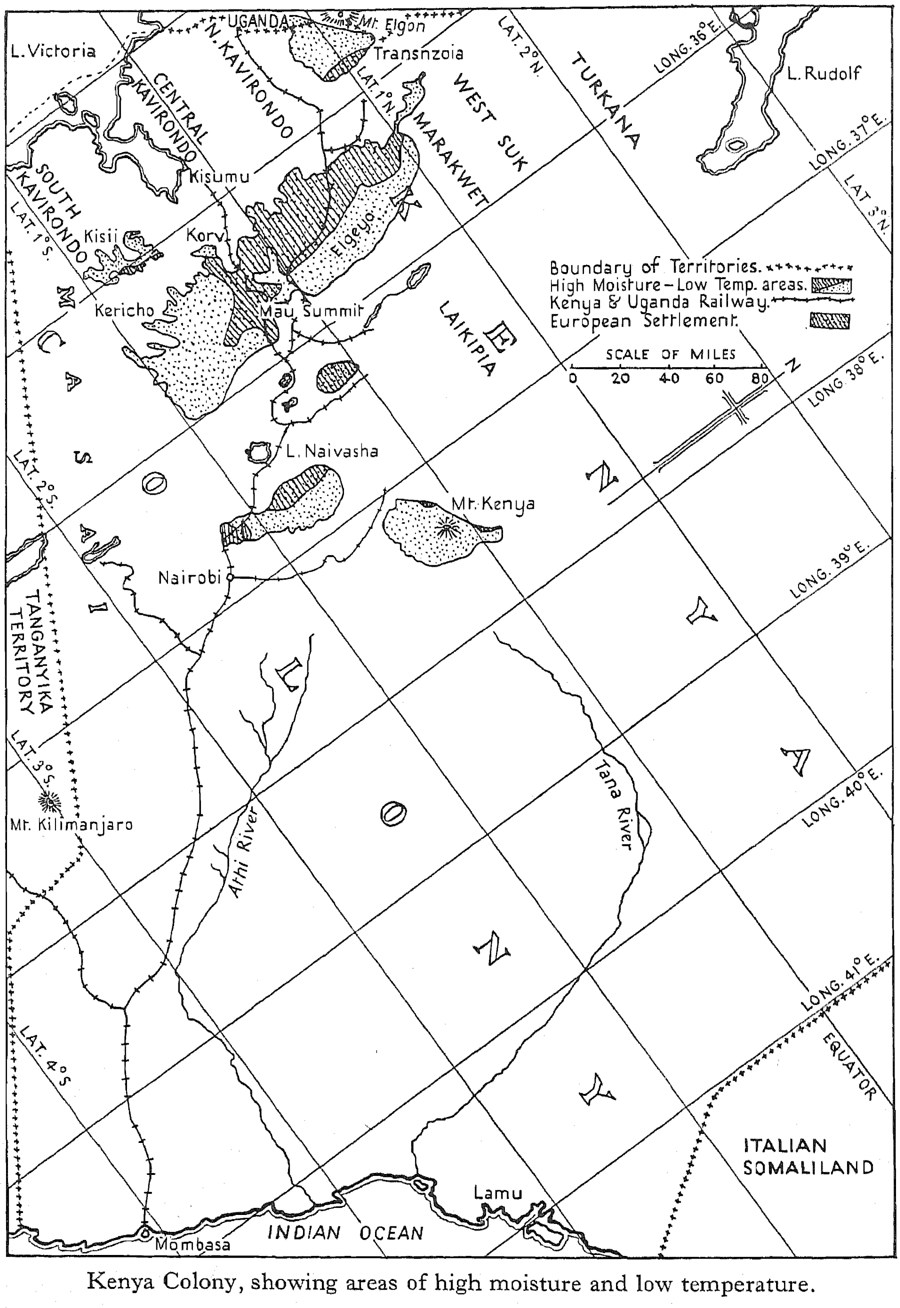
THE greatest potential asset of Kenya lies in its natural grasslands which constitute approximately one-half of the total land surface of 219,730 square miles. This estimate of the grasslands excludes vast semi-arid areas which, although they support large quantities of game and the herds belonging to nomadic tribes, are never likely to lend themselves to any considerable degree of development owing to lack of sufficient moisture.

Types of grassland.—There are two main types of grassland to be considered. The more important from the point of view of area consists of a natural herbage dominated by *Themeda triandra* Forsk. This type occupies extensive open plains and usually constitutes a savannah in which *Acacia* trees are prominent, although considerable areas exist in which few *Acacia* trees occur. This type of vegetation is produced under conditions of erratic rainfall and periodical droughts. It is to some extent influenced by the fires which sweep over parts of it, but there are at least considerable portions of this country in which the vegetation can be regarded as a climatic climax.

In comparatively small areas, however, this type of grassland has been greatly affected by the biotic factor of man and his grazing animals. In these areas over-grazing has resulted in the dominance of other grasses such as *Aristida* and *Eragrostis*.

The other main type is that associated with the high-moisture and comparatively low-temperature conditions obtaining at the higher altitudes. The climax vegetation of this type of country is forest; but over considerable areas the forest has been cleared, either in fairly remote times by native stock-owning tribes or more recently by European settlers. Wherever the forest has been removed, grassland stages of the plant-succession ensue. The grasslands falling within this vegetational type most readily lend themselves to development, and they will therefore form the main subject of the present description, which is the first of a series on the grasslands of Kenya. The limiting factor in production in these areas is soil fertility, in contradistinction to the vast *Themeda-Acacia* grasslands, where moisture is most important.

In addition to these two main types there are other zones of vegetation less important from a grassland point of view. One of these occurs under high-rainfall conditions at lower altitudes as, for instance, in the region of Lake Victoria Nyanza. Country of this type is occupied mainly by agricultural native tribes. The growth of vegetation is rapid and vigorous, approaching the tropical rain-forest type, and there is, over the greater part of such areas, no important grassland stage in the plant-succession. Whenever cultivated land is abandoned in this type of country there follows a rapid growth of dense bush. There are again



Kenya Colony, showing areas of high moisture and low temperature.

further areas which may be regarded as transitional between the two main types of vegetation described above. In these areas the most common dominant in the herbage remains *Themeda triandra*, although in other respects the vegetation differs from the *Themeda-Acacia* savannah.

The areas of high moisture and low temperature.—These comparatively small areas of the country are associated with the relatively high-moisture and low-temperature conditions of the higher altitudes. The extent of the vegetational area concerned is estimated as 7,000 to 8,000 square miles, of which approximately 2,500 square miles are occupied by European farms. In all the areas under consideration there is a rainfall of roughly from 40 to 60 in., fairly well distributed throughout the year, and the altitudes range from 6,500 ft. to 9,000 ft. and more. These high altitudes, of course, imply comparatively low temperatures. The moisture conditions are actually more favourable than indicated by the scanty meteorological data available, since, in addition to the rainfall, frequent mists, often almost daily in occurrence, contribute to the supply of moisture. The accompanying map shows the distribution and approximate size of the areas that fall within the above description. The areas demarcated include, of course, mountain masses, the higher parts of which do not support this particular vegetational type.

The plant-succession.—Practically the whole of these areas may be regarded as potentially Kikuyu grass (*Pennisetum clandestinum* Hochst.) country, and it will be seen from the following account of the plant-succession that, where herbage composed of this grass does not already exist, it can, in most cases, be produced.

It is interesting to note here that the distribution of *P. clandestinum* is an extremely limited one. It is recorded as occurring naturally only within the tropics in East Central and North-East Africa [1], and even here it is confined to small areas of very special moisture and temperature conditions.

The whole of this vegetational zone in Kenya was, as already indicated, at one time almost entirely under forest, and considerable parts are yet in this condition. The forest varies somewhat in composition, but some of the characteristic trees are—*Olea chrysophylla* Lam.; *Olea Hochstetteri* Baker; *Podocarpus* spp.; *Lachnopylis congesta* C.A.Sm.; *Pygeum africanum* Hk.; *Dombeya Mastersii* Hk., and in the drier parts, *Juniperus procera* Hochst.

Immediately following the clearance of this forest, a herbage consisting of *Pennisetum clandestinum*, generally with a proportion of *Trifolium Johnstonii* Oliv., is formed. After a period, varying probably in different parts, this stage in the plant-succession gives place to a stage consisting mainly of coarse, tufted grass species. The most prominent of these over large areas is *Pennisetum Schimperi* A. Rich., and in smaller localized areas *Eleusine Jaegeri* Pilger.

Associated with the former an *Agrostis* sp. is frequently found and, in certain areas, for instance the Kinankop Plateau, *Andropogon chrysostachyus* Steud. is important. The two last-mentioned are both finer grasses. The coarse-grass stage of the succession appears to persist for a very considerable period and large parts of the areas under considera-

tion at present fall into this category. Following this stage, the next retrograde step is to a herbage in which *Themeda triandra* Forsk. is dominant. The greater part of the grasslands here considered have reached this last stage.

Factors influencing the plant-succession.—The changes outlined above are clearly connected with falling soil fertility and there is considerable evidence pointing to organic matter as the controlling factor.

The *Pennisetum clandestinum* stage of the plant-succession is associated with conditions of high soil fertility such as are produced under forest. The other stages can be explained by a gradual fall in fertility, particularly with regard to organic matter. The changes probably vary in rapidity with the amount and nature of the rainfall experienced. Another factor believed to play an important part, particularly in the production and maintenance of the *Themeda triandra* stage, is periodical grass-burning which, in many areas, has probably taken place under native occupation over a great many years. Fire was undoubtedly the instrument by which the forest was originally destroyed over large parts of these regions.

In the vegetational zone under consideration the *Themeda triandra* herbage is unstable and distinctly sensitive to increase of soil fertility with regard to organic matter; that is, an increase in fertility results in the appearance of species belonging to the higher *Pennisetum Schimperi* stage. This change has already taken place in the immediate neighbourhood of the homesteads of European-owned farms as the result of the animal manure deposited. Small areas of coarse and extremely tufted herbage are almost always to be found in these places, although the natural pasture of the district in general may be dominated by *Themeda triandra*.

There is clear evidence that the retrogression from *Pennisetum clandestinum–Trifolium Johnstonii*, through the coarse *Pennisetum–Eleusine* to the *Themeda* stage, can be arrested and that the higher grass-stages of the succession can readily be induced to return. The ease of accomplishing the change back to the desirable sward of Kikuyu grass and clover naturally depends upon the extent to which retrogression has taken place, but in all the areas examined, concentration of animals, and the consequent deposition of manure, bring about a rapid change in the herbage. On the sites of old native *bomas* (herding places), and where night herding paddocks have been situated on European-owned farms, a return to the *P. clandestinum* stage has very frequently taken place, whether these sites be on herbage dominated by *P. Schimperi* or *T. triandra*. Small areas where *Eleusine Jaegeri* is strongly dominant are probably due to higher fertility conditions than those which support a *Pennisetum Schimperi* herbage.

Cultivation, or any stirring of the soil, temporarily produces higher fertility and usually results in an increase of species belonging to higher stages in the succession than the one in existence. This fact may account for the presence of the two large tufted species and of *P. clandestinum* at roadsides in areas in which they are not generally dominant.

It is evident, then, that from a grassland point of view, there are no

essential differences between these areas of high moisture and low temperature in various parts of the country. The present variation between individual areas is accounted for by variations in the length of the period during which the vegetation has been retrogressing from the forest climax, as a result of the leaching of nutrients from the soil since the destruction of forest.

Agricultural value of the species concerned.—As regards the value of the different types of herbage produced during the process outlined above, the *Pennisetum clandestinum–Trifolium Johnstonii* stage and the *Themeda triandra* stage are the two of known value for grazing. The former, however, is the only one suited to intensive management. *Themeda* forms an entirely different type of sward from the stoloniferous Kikuyu grass, in which there is usually a fairly high proportion of bare ground. Apart from this, it has already been pointed out that *Themeda* herbage is decidedly unstable in the areas under consideration, and the concentration of grazing animals rapidly results in the appearance of the coarse grasses *Pennisetum Schimperi* and *Eleusine Jaegeri*. These two species are both extremely coarse and unpalatable and are of little value as pasture grasses.

Since dairy farming seems the obvious development in these higher areas of the country, management should be directed to the production and maintenance of Kikuyu grass (*P. clandestinum*) and indigenous clover pastures. This type of sward is capable of withstanding heavy grazing; in fact, the two species concerned thrive under these conditions and the concentration of stock is necessary to the maintenance of the stage.

It is important to note also, that in none of the lower stages of this succession is there an adequate proportion of legumes in the herbage. In these stages clovers are practically non-existent and other legumes are uncommon. In addition to *Trifolium Johnstonii*, other clovers such as *T. repens* L., *T. semipilosum* Fresen., and *T. usambarense* Taub. are found in association with Kikuyu grass. The only clover of importance, however, is *T. Johnstonii*, except possibly *T. repens*, in certain small areas at 8,000 to 9,000 ft. altitude.

For those who are not familiar with *Pennisetum clandestinum*, a brief description will give a clearer idea of the type of sward produced by this grass. It is of a creeping habit and spreads by means of stout-branched surface-runners, which root very readily at the nodes, and also by underground stems. An abundance of leaf is produced which, when ungrazed on good soil, may reach a foot or 18 in. in height. When kept down by grazing or cutting an extremely close-growing sward is formed. In addition to roots this grass has an extensive underground system of stems, and since the latter often penetrate to a foot or more below the surface, it is not surprising that the plant is capable of withstanding heavy grazing; this, together with its high leaf-yield and ability to recover quickly, makes it admirably suited to intensive management.

Management.—The key to the management of this type of grassland is believed to be control of the organic-matter content of the soil. Where the Kikuyu grass-clover sward still remains, live stock must be concen-

trated and the grazing managed on a rotational basis, so that the whole of the pasture utilized has full benefit of the manure produced. Unless this is done there is constant danger of the advance of the coarse *Pennisetum* and *Eleusine*. In places where the succession has not fallen back beyond this coarse intermediate stage, heavy concentration of stock and close grazing will do much to bring about the return of Kikuyu grass, providing the animal droppings are allowed to accumulate on the pasture. Apart from the effect of the manure, the grazing will also have a suppressing effect on the coarse species. The rotation of night herding paddocks over the area it is desired to convert may be a feasible means of improvement in the first instance. Where the succession has fallen back to the *Themeda triandra* stage, which is the case over the greater part of these areas of high moisture and low temperature, the first effect of concentrating animals, even to a small degree, is the return of the undesirable intermediate stage of coarse grasses, and under these conditions, this stage is very persistent. Greatly increasing the soil organic matter and, at the same time, trampling the surface bare, such as by folding sheep, has the effect of causing a return of Kikuyu grass but, in general, on *Themeda* land it is probable that the only satisfactory way of producing Kikuyu-grass pastures will be to plough up, thoroughly clean the land, and at the same time increase the fertility as much as possible by the addition of farm-yard manure, or by heavy concentration of animals on the area prior to cultivation. Kikuyu grass will then advance naturally, but planting pieces of the runners accelerates the production of a sward.

Given Kikuyu grass-clover pastures under proper rotational management of close grazing and periodical rests, there is little doubt that the use of the mineral manures necessary to intensive grazing will become an economic proposition. In fact, it is most probable that phosphatic manures, acting on the clover, would assist in the maintenance of the reserves of organic matter that are essential to the success of this stage of the succession [2]. We have, at any rate, in this grass and clover sward, an obviously efficient instrument for the conveyance of the minerals to the animals and, providing the animals used are of sufficiently high-yielding types, there is every reason to expect success. Under the present conditions of haphazard and extensive management mineral manuring cannot be contemplated.

Discussion

The areas considered are comparatively small, but the possibility of development of their pasture resources is far greater than in most of the remaining part of the country, where development is limited by low and erratic rainfall. It is in these areas that dairy farming (by Europeans in the first instance) can be expected to grow if the advance to intensive methods can be accomplished. Some of the most important stock-farming districts are already to be found within this type of country. They include Molo, the Kinankop Plateau, Upper Gilgil, and part of the Thomson's Falls area, apart from a number of districts of lesser importance.

Although the stages of the plant-succession described are common to the areas of high moisture and low temperature in general, exceptional soil conditions are sometimes encountered, as for instance where poor drainage occurs, which may have the local effect of inhibiting the development of the higher stages. Observations have been made in all the areas shown on the map with the exception of the comparatively small one to the south-west, and Kikuyu grass is known to be dominant in parts of this area.

The plant-succession consists of the following stages:

1. Cool forest
2. *Pennisetum clandestinum–Trifolium Johnstonii*
3. *Pennisetum Schimperi–Eleusine Jaegeri*
4. *Themeda triandra*

High fertility ↑↓ Low fertility

The *P. clandestinum–T. Johnstonii* stage provides a sward well suited to intensive grazing, and this sward can be obtained and maintained fairly readily.

As may be expected, this superior type of pasture demands higher soil fertility, and it seems fairly evident that the controlling factor is organic matter. Indeed, it is becoming increasingly evident that this aspect of soil fertility is of major importance in all parts of the country. Experiments have been designed to establish whether or not organic matter is the all-important factor in the control of the plant-succession in these areas, but the evidence is already so strong that it is not considered necessary to await the results of these experiments before applying the main principles of management indicated by this preliminary study of the plant-succession.

Acknowledgement

Grateful acknowledgement is made of the assistance given by Mr. G. H. G. Jones, Soil Chemist of this Department, with whom matters relating to soil fertility were discussed.

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THE DEVELOPMENT OF THE MARKET FOR BEEF IN GREAT BRITAIN

K. A. H. MURRAY and J. A. SCOTT WATSON

THE last sixty years have witnessed a rapid growth in this country's meat requirements. Reliable estimates are not available for the period before 1871, but in that year Howard calculated that the total meat-supply, consisting of beef, mutton and lamb, and pig-meat, was about 989,000 tons, of which 83 per cent. or 841,000 tons was home-produced.[1]

Various estimates of the meat output from British farms have been made from time to time, notably by Rew and by Hooker. Many of these have been revised in the light of later improvements and the official computations for annual supplies since 1900–1 are available in various reports. In order to bridge the gap between 1871 and 1900–1, estimates have been made for 1880–1 and 1890–1 on the same basis as the more recent official calculations. A few assumptions were necessary, but the results seem reasonable. The changes in total supplies are given in Table 1, the War years being omitted as abnormal.

TABLE 1. *Estimated Annual Meat-Supplies of Great Britain*

Period	*Home output**	*Imports*	*Total*	*Per capita consumption*
	tons	tons	tons	lb.
1871	841,000	148,000	989,000	85
1880–1	963,000	444,000	1,407,000	106
1890–1	992,000	648,000	1,640,000	111
1900–1 to 1904–5	1,147,000	1,168,000	2,315,000	137
1905–6 to 1909–10	1,169,000	1,170,000	2,339,000	132
1910–11 to 1913–14	1,157,000	1,202,000	2,359,000	128
1923–4 to 1927–8	1,115,000	1,565,000	2,680,000	137
1928–9 to 1932–3	1,154,000	1,651,000	2,805,000	141

* Including edible offal.

There was a very rapid increase in supplies during the seventies of last century, the total rising by about 400,000 tons or 40 per cent. During the next decade the increase was less marked, but between 1890 and 1900 the market expanded very rapidly again and in the first five years of the twentieth century the annual meat-supply averaged 2,315,000 tons, an increase of 134 per cent. in thirty years.

The home output of meat had risen about 34 per cent. in that period, the increase being faster in the seventies and nineties than in the eighties. While the home output had increased by about 300,000 tons, imports had risen almost eightfold.

During the twentieth century total supplies have continued to increase, but the expansion has by no means been so spectacular. Home production has remained relatively stable, whilst imports have continued to

[1] Howard, James. *Our Meat Supply*. Bedford, 1876.

rise, though less rapidly than in the earlier years. In the last five-year period of the table, 1928–9 to 1932–3, the total supply averaged 2,805,000 tons, of which 1,154,000 tons were produced in Great Britain and 1,651,000 tons were imported.

The four main factors in the growth of the market for meat are—(*a*) the increase in population; (*b*) changes in consumers' spending power; (*c*) changes in the prices of meat relative to other foods; and (*d*) changes in food habits and tastes. So far as total meat is concerned, it is intended to discuss briefly only the first two of these factors.

Between 1870 and the beginning of the twentieth century, a great part of the growth in meat requirements must be attributed to the increase of population. In the forty years 1871–1911 the population increased by 14,759,000, but during the next twenty years, which included the War period, the increase was only 4,000,000. It is generally believed that the rate of population increase will continue to decline and that a stationary or even a declining population may be expected in the near future.

TABLE 2. *Population Increases in Great Britain, 1871–1931*

Census year	*Population*	*Increase over previous census*
		per cent.
1871	26,072,000	..
1881	29,710,000	13·9
1891	33,029,000	11·1
1901	37,000,000	12·0
1911	40,831,000	10·4
1921	42,769,000	4·7
1931	44,831,000	4·8

The *per capita* consumption of meat in Great Britain is also given in Table 1. Between 1871 and 1880 it increased from 85 lb. to 106 lb., and again rose, to 111 lb., in the next ten years. Then followed another rapid increase until, in the five years 1900–1 to 1904–5, it averaged 137 lb. During the following quinquennium consumption declined, but in the post-War period it recovered and eventually passed its pre-War level.

There is little doubt that these changes in *per capita* consumption are closely related to changes in incomes, especially in the pre-War years. From 1870 until 1898 there was a very marked rise in the purchasing power of wages, and there is strong evidence that higher incomes resulted in a greater consumption of, and a greater expenditure on, meat in general.[1] Post-War data also indicate that consumption increases with income[2] and there is reason to believe that the limiting factor to con-

[1] *Second Report of the Committee to Enquire into the Production and Consumption of Meat and Milk in the United Kingdom.* Journal of the Royal Statistical Society, vol. lxvii, part iii, 1904, and *Report of the Royal Commission on the Supply of Food and Raw Materials in Time of War*, Cmd. 2645, 1905.

[2] Short, J. B. *An Analysis of Customers' Purchases of Beef, Mutton, and Pork in a Rural District of Cambridgeshire, 1928.* Unpublished manuscript; and Jones, A., and Makings, S. M., *Some Aspects of Meat Distribution and Consumption.* Midland Agricultural College, Sutton Bonington, 1931.

sumption by the lower-income groups is their smaller incomes rather than any innate difference in food tastes.

Total annual requirements in the years 1928–9 to 1932–3 averaged 1,816,000 tons more than in 1871; about 712,000 tons, or 39 per cent., of the increase was due to increased population, and the balance of 1,104,000 tons, or 61 per cent., to increased *per capita* consumption.

Examination of these two factors suggests that the continued expansion of total meat requirements in the future will depend primarily on an increase in *per capita* consumption rather than on any considerable growth in population; and though the rate of increase in *per capita* consumption may become progressively slower, an increase is still possible, provided consumers' spending power increases and standards of living rise.

Beef and Veal

(*a*) *Supplies.*—During the last fifty years beef and veal have comprised slightly less than one-half of Britain's total meat-supplies, though this proportion has varied from time to time.

No reliable estimates can be formed of the annual supplies of beef and veal before the last quarter of the nineteenth century. In 1880–1 the annual requirements were about 565,000 tons, of which 75 per cent. was home-produced; *per capita* consumption was about 43 lb. a year. During the next ten years supplies increased slightly faster than population, and consumption rose from 43 lb. to 49 lb.; the consumption of the other meats remained relatively steady. Home production did not increase materially, but imports were almost doubled.

TABLE 3. *Estimated Supplies of Beef and Veal in Great Britain*

Period	*Home output*	*Imports*	*Total*	*Per capita consumption*
	tons	tons	tons	lb.
1880–1	415,000	150,000	565,000	43
1890–1	425,000	293,000	718,000	49
1900–1 to 1904–5	612,000	513,000	1,125,000	67
1905–6 to 1909–10	642,000	545,000	1,187,000	67
1910–1 to 1913–4	621,000	585,000	1,206,000	65
1923–4 to 1927–8	602,000	775,000	1,377,000	70
1928–9 to 1932–3	607,000	717,000	1,324,000	66

There followed a period of rapid expansion during the next fifteen years; both the home output and imports increased and *per capita* consumption rose; total meat-consumption during this period rose by 26 lb. (Table 1), so that beef more than held its own with an increase of as much as 18 lb.

Until the War consumption of beef remained nearly constant, while there was a marked drop in that of other meats. Home production reached a peak of 654,000 tons in 1909–10 and afterwards declined considerably; imports, on the other hand, continued to increase, and were responsible for the maintenance of the total *per capita* consumption.

In the post-War quinquennium, 1923–4 to 1927–8, consumption had

risen to an average of 70 lb. per head; once again the home output had declined, but imports had risen by an amount that more than compensated for the decline in home production. While beef-consumption had risen 5 lb. between the two periods, the consumption of other meats had risen 4 lb. At this stage beef constituted 51 per cent. of the total meat consumed.

Since 1925–6 there has been a decline in beef-supplies, both absolutely and in relation to population. Home production had risen slightly but not sufficiently to offset the decline in imports. *Per capita* consumption averaged only 66 lb. compared with 70 lb. in the previous five years. Actually the annual consumption fell from 71·6 lb. in 1925–6 to 62·2 lb. in 1932–3. During the same eight years, the consumption of mutton and lamb rose from 25·6 lb. to 33·7 lb., and of pig-meat from 38·7 lb. to 47·8 lb.

In the period 1928–9 to 1932–3 annual beef requirements were 759,000 tons a year greater than in 1880–1, and of this increase 296,000 tons a year (or 39 per cent.) was due to growth in population, and 463,000 tons (or 61 per cent.) to higher *per capita* consumption.

Table 4 summarizes the average annual supplies for the four years 1927–31. About 45 per cent. of the total was home-produced beef, including cattle fattened from imported Irish stores.

TABLE 4. *The Constitution of Great Britain's Beef-Supply, 1927–31*

Class	*Cwt.*	*Per cent. of total*
Home-fed cattle	12,430,000	45·3
Imported fat cattle	2,025,000	7·4
Imported chilled beef	9,530,000	34·7
Imported frozen beef	2,732,000	10·0
Other types	718,000	2·6
Grand total	27,435,000	100·0

Reference to Table 5 shows that, in the five years 1923–4 to 1927–8, about 50 per cent. of the cattle slaughtered annually in England and Wales were steers and maiden heifers, assuming that all the stores imported from Ireland came into these categories; about 46 per cent. were cows, and the remaining 4 per cent. were 'baby beeves' and bulls. In the pre-War period only about 37 per cent. were cows; steers, maiden heifers, and bulls (including Irish imported as stores) accounted for 63 per cent. of the slaughterings compared with 54 per cent. in the post-War years.

Imported fat cattle, coming principally from the Irish Free State and to a lesser extent from Canada, were practically the only other source of fresh beef competing directly with the home product; these provided about 7·4 per cent. of the total beef-supplies. Chilled beef, which is the most important indirect competitor with fresh beef, formed 34·7 per cent. of the supply. About 90 per cent. of this came from the Argentine, the remainder being mainly from Uruguay and Brazil. Imported frozen beef formed 10 per cent. of the total; about 35 per cent. came from the Argentine, 34 per cent. from Australia, 12 per cent. from New Zealand, and small quantities from Uruguay, Brazil, and a few other countries.

Imports of other types such as salted, tinned, and canned beef were insignificant, and amounted to less than 3 per cent. of the total.

TABLE 5. *Estimated Numbers of Cattle Fattened and Slaughtered in England and Wales, 1908–9 to 1912–3 and 1923–4 to 1927–8*[1]

	1908–9 to *1912–3*		*1923–4* to *1927–8*	
	Numbers (thousands)	*Per cent.*	*Numbers (thousands)*	*Per cent.*
Cows	515	37·3	600	46·4
Steers and maiden heifers	601	43·5	387	29·9
Baby beeves	*	*	30	2·3
Bulls	†	†	21	1·6
Irish imported as stores	265	19·2	256	19·8
Total slaughtered	1,381	100·0	1,294	100·0

* No estimate available, but negligible. † Included in steers.

(*b*) *Price movements.*—Three principal types of price changes may be distinguished: long-term movements, year-to-year fluctuations, and seasonal variations.

The long-term movements follow fairly closely the movements of prices in general and, in so far as they conform with them, may be attributed to the common causal factors. In so far as they diverge from the trend of the general price level, the movements may be explained by the supply and demand factors for beef, or for different types of beef.

Between 1904 and 1913 the general level of wholesale prices moved slowly upwards at the rate of about 0·93 per cent. per annum. The changes in beef prices during this decade are shown in Table 6, col. 1.

TABLE 6. *Annual Increase or Decrease in the Price of Different Types of Beef and in the General Price Level, 1904–13, 1923–9, and 1929–34*

(expressed as a percentage of the average price of each type in each period)

	Percentage change per year		
	1904–13	*1923–9*	*1929–34*
British beef, first quality	+0·82	−2·55	−2·63
Cow and bull beef, first quality	+2·82*	−2·54	−3·43
Argentine chilled beef, hind-quarters	+0·92	+1·68	−2·84
Australian frozen, hind-quarters	+1·14†	+0·58	−4·78
General price level	+0·93	+2·68	−3·46‡

* 1907–13. † Argentine frozen.
‡ The decline in wholesale prices occurred mainly in 1930.

The variations in the rates of increase cannot reasonably be attributed to changes in the volume of supplies of the various types. Frozen-beef supplies were still increasing rapidly, as well as those of chilled beef, which was then still a relatively unimportant factor on the market; home

[1] From the *Report on the Marketing of Cattle and Beef in England and Wales*, Economic Series No. 20, Ministry of Agriculture, 1929.

production rose between 1904 and 1910, and only in the three remaining years did it decline slightly.

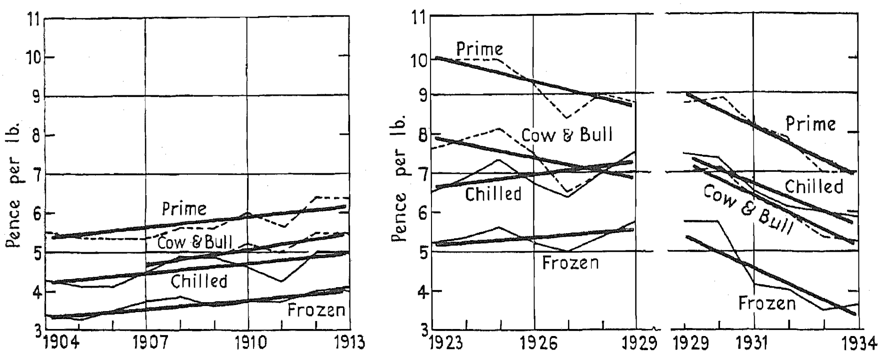
Changes in demand rather than in supplies appear to explain both the general increase in beef-prices and certain of the divergencies between one type and another; between 1896 and 1914 general prices rose in terms of gold; fluctuations in the value of money cause changes in money incomes, and thus affect commodity prices through the demand factor. Furthermore, during the period in question prices rose more rapidly than did money wages, or in other words there was some decline in real wages; much of the demand for first-quality beef would therefore probably be transferred to the poorer qualities, and this would account for the more rapid rise in the prices of frozen beef, the main type of imported beef at that time, and of cow and bull beef, than in the price of first-quality British beef. This theory is borne out by an examination of prices during the years 1873 to 1896; in that period general prices were falling, wages lagged in the fall, the purchasing power of wages increased, demand for first-quality beef was relatively strong, and the price of prime beef fell less rapidly than the prices of inferior qualities.

Coming to the post-War period, 1923–34 (Table 6, cols. 2 and 3), the long-term movements in the prices of the different types were very divergent. The twelve years have been divided into two periods, 1923–9 and 1929–34, the former covering the years when the general decline of prices was more or less steady, the latter a period of more rapidly falling prices. This division makes the straight-line trends more representative of the various price series.

During the seven years 1923–9 beef-prices fell as prices in general declined. Once again the total supply was not the main responsible factor; total money demand decreased during this period of deflation. Prime British beef fell in price at the rate of 2·55 per cent. per year and cow and bull beef 2·54 per cent.; home-production showed an upward trend during the period. Argentine chilled beef, on the other hand, showed an upward price trend during the period, 1·68 per cent. per year, in spite of a very rapid increase in supplies until 1927–8. There is no doubt that during these years there was a very strong change-over on the part of certain classes of consumers, particularly in the cities, towards the chilled product—on account, presumably, of its uniformity and improved quality. It may, in fact, be true that, for some classes of consumers, taste is a more decisive factor in demand than relative cheapness. The same period witnessed the rapid expansion of the dairy industry in this country and a consequent decline in the quality of home-produced beef. These two factors were responsible for the maintenance of chilled-beef prices at a time when home-beef prices were falling rapidly. By the end of the period chilled-beef prices had risen above the level of cow and bull beef, supplies of which were forming an increasing proportion of the home output.

Frozen-beef prices showed a slight upward trend during the period, due mainly to a decline in supplies which continued during the entire seven years. The market for frozen beef is possibly limited, particularly when other meats are relatively low in price.

The movements since 1929 (Table 6, col. 3) have all been in the same downward direction, following the general price level, but again they have varied for different types of beef. Frozen beef fell most rapidly, then cow and bull beef, next chilled beef, and finally prime British beef. The most reasonable explanations of the relative movements are again connected mainly with changes in demand. The rapid fall in British beef prices in the earlier period had brought them down to a level at which those consumers for whom price rather than taste is the deciding factor could compete for it; and this, one may argue, would tend to slow down the fall in prime-beef prices.



Trends in the Prices of British and Imported Beef in England and Wales, 1904–13, 1923–9, and 1929–34.

For example in 1929 British prime beef was $8\frac{3}{4}d.$ per lb. at wholesale, and chilled Argentine hind-quarters $7\frac{1}{2}d.$; by 1933 British prime beef had declined to less than the 1929 price for Argentine chilled. Allowing for the general reduction in consumers' purchasing power between 1929 and 1933, the consumer paying $7\frac{1}{2}d.$ in 1929 could afford about $6\frac{3}{4}d.$ per lb. in 1933 and this brought him within reach of British beef in 1933.

Similarly, with prices at a lower level, a considerable change-over might be expected from frozen beef to chilled beef, which, coupled with the increasing supplies after 1931, would weaken considerably the frozen-beef market.

In summary, therefore, the price movements of the different types of beef indicate that there is very considerable changing over in the consumption of different types. Relative supplies play a small part in affecting the trends, but changes in demand provide the major explanation. Pre-War movements show a transference of demand to the cheaper types during the period of rising prices and declining purchasing power. The first half of the post-War period showed a rapid swing-over to chilled beef, mainly at the expense of fresh British beef. The figures for the latter half of the period suggest a further swing to chilled beef, but possibly rather at the expense of frozen beef and of home-produced cow and bull beef, the decline in the prices of the higher qualities during the earlier period having brought these types within the potential purchasing power of lower-income groups of consumers.

During the last few years home-produced beef has met competition not only from cheaper types of beef but also from mutton, which has normally been considerably above the price level of the corresponding quality of beef, but which has recently been at a competing level.[1] Table 7 indicates the movements in retail prices of approximately similar qualities of home-produced and imported beef and mutton.

TABLE 7. *Representative Retail Prices of Home-produced and Imported Beef and Mutton in Great Britain*

(in pence per lb.)

	Home-produced						*Imported*				
	Ribs of beef		*Legs of mutton*		*Flank of beef*	*Breast of mutton*	*Ribs of beef*	*Legs of mutton*		*Flank of beef*	*Breast of mutton*
	s.	*d.*	*s.*	*d.*	*d.*	*d.*	*d.*	*s.*	*d.*	*d.*	*d.*
1923–5	1	$5\frac{3}{4}$	1	$8\frac{1}{6}$	$10\frac{1}{12}$	$11\frac{5}{12}$	$10\frac{1}{3}$	1	$0\frac{5}{12}$	$5\frac{2}{3}$	$5\frac{1}{3}$
1926–8	1	5	1	$6\frac{5}{12}$	$9\frac{5}{12}$	$10\frac{1}{12}$	$10\frac{1}{12}$		$11\frac{7}{12}$	$5\frac{5}{12}$	$5\frac{1}{12}$
1929–31	1	4	1	$5\frac{5}{6}$	$8\frac{11}{12}$	$9\frac{3}{4}$	$10\frac{1}{4}$		$11\frac{1}{4}$	$5\frac{7}{12}$	5
1932	1	$2\frac{3}{4}$	1	$3\frac{1}{4}$	8	8	$9\frac{3}{4}$		$9\frac{1}{2}$	$4\frac{3}{4}$	4
1933	1	2	1	$2\frac{1}{2}$	$7\frac{1}{2}$	$7\frac{1}{2}$	9		$9\frac{1}{4}$	$4\frac{1}{2}$	$3\frac{3}{4}$
1934	1	2	1	3	$7\frac{3}{8}$	$7\frac{1}{2}$	9		$9\frac{1}{2}$	$4\frac{1}{2}$	$3\frac{3}{4}$

In 1923–5 British ribs of beef were 1*s.* $5\frac{3}{4}$*d.* per lb. and legs of mutton about 1*s.* $8\frac{1}{6}$*d.*, a difference of $2\frac{5}{12}$*d.* per lb.; by 1933 mutton had declined to within $\frac{1}{2}$*d.* per lb. of the price of ribs of beef. Similar relative changes occurred for poorer qualities of home-produced beef and mutton.

Imported leg of mutton averaged 1*s.* $0\frac{5}{12}$*d.* per lb. in 1923–5 compared with $10\frac{1}{3}$*d.* per lb. for imported ribs of beef, a price difference of $2\frac{1}{12}$*d.* per lb.; by 1933 mutton had declined to $9\frac{1}{4}$*d.*, while beef had fallen only to 9*d.*, the price difference being reduced to $\frac{1}{4}$*d.* per lb. Between 1924–5 and 1933 the *per capita* consumption of mutton and lamb rose from 24·2 lb. to 32·1 lb., while that of beef dropped from 70·1 to 62·0 lb. The maintenance of real wages during the period of declining prices, coupled with the more rapid drop in mutton prices than in those of beef, has resulted in a considerable change-over from beef-consumption. There has also been some change of taste in favour of mutton and lamb, which has accentuated the change resulting from the change in relative prices.

Though there are considerable differences in the long-term price trends for the different types of beef, there is a very striking similarity in their year-to-year fluctuations, which suggests the operation of one or more factors exerting a common influence. Home-produced and imported, fresh, chilled, and frozen beef tend to move in the same direction in any one year, though by varying amounts. Supplies of the several types do not vary together, and correlation studies show little relationship between supplies and prices. Once again the importance of the demand factor must be emphasized. It seems as if there is a considerable amount

[1] Wholesale mutton prices have experienced a sharp rise during recent months and this will probably be reflected in higher retail prices for 1935.

of substitution in the demand for the different types; a rise in the price of dearer beef is reflected in a rise in price of the cheaper by means of a transference of consumer demand. Similarly, a drop in the price of any one type will effect a corresponding move in those of the others.

During the last four or five years, as is shown in Table 8, total supplies of beef, mutton, and lamb, taken together, have remained remarkably steady, varying by no more than 2 per cent. from the average of the three years 1927–9. Prices, on the other hand, declined by 26 per cent. between 1930 and 1933, this being, it is suggested, the result of decreased spending power. The slight upturn in spending power since 1933 was accompanied by an upturn in combined prices in 1934; the rise, however, was accounted for by mutton and chilled beef only, and was not shared by fresh beef; supplies of the two former were less than in 1933, but fresh beef-supplies were greater.

TABLE 8. *Index Numbers of* (1) *Combined Supplies of Beef, Mutton, and Lamb,* (2) *of Combined Prices, and* (3) *of Consumers' Spending Power, 1927–9 to 1934*

(1927–9 = 100)

	*Supplies**	*Price†*	*Spending power‡*
1930	100	102	97
1931	98	90	90
1932	99	81	88
1933	98	76	90
1934	..	79	93

* Including home output, imported chilled and frozen beef, live fat cattle, frozen mutton and lamb, and live sheep.
† Weighted according to the 1930–1 total values of each type included.
‡ Based on wage earnings and numbers employed with an allowance for rent payments.

The third type of price movement is seasonal variation, and so far as this is concerned variation in supply exercises an important effect. Meat consumption as a whole alters remarkably little throughout the year, though there is considerable variation for individual products.[1] During the summer months there is, in general, a greater demand for lighter meats such as veal, lamb, poultry, &c., and in the winter months a preference for beef and pork.

The index numbers of monthly supplies of beef and veal in Great Britain are given in Table 9. The peak of supplies, occurring in October, was 10 per cent. above the average monthly quantity, and in the following three months nearly the same level was maintained. The lowest figure, 12 per cent. below the average, occurred in June. It may be noted that the seasonal variation in supplies is considerably greater for home-killed beef, the monthly indices of which vary between 121 and 78, than for imported beef, the highest and lowest indices for which are 105 and 90. It does not follow that consumption of imported beef is more steady throughout the year, because considerable amounts of imported frozen

[1] Data on these variations are given in the *Report of the Reorganization Commission for Fat Stock for England and Wales*, Economic Series No. 39, Ministry of Agriculture and Fisheries, 1934.

meat may be stored; it is probable, however, that imported supplies do tend to balance out the irregularity of the home output, since the main part of the imported supply is chilled beef, which moves into consumption almost immediately on arrival.

TABLE 9. *Index Numbers showing the Seasonal Variation in Beef and Veal Supplies in Great Britain, 1927–31*[1]

(Monthly average = 100)

Month	*Home-killed*	*Imported*	*Total*
January	113	104	109
February	96	92	94
March	100	103	102
April	93	101	97
May	87	105	95
June	78	100	88
July	83	102	91
August	93	103	98
September	103	99	101
October	117	102	110
November	121	90	107
December	116	99	108
Monthly average	100	100	100
Standard deviation	13·6	4·4	7·1

The question of seasonal variation is of great importance to the home industry, particularly because there is a growing tendency for market supplies to be concentrated in the autumn months, and the volume of the home output is at that time the main price-determining factor. The increasing concentration is due to the change in production methods from winter fattening on arable-land products to summer grass-feeding.

The following figures show, for example, what has occurred during the last twenty years at Norwich market, in the centre of a large arable farming, winter-fattening area. In the pre-War period, 11,463 cattle, winter-fed, were received in the first quarter of the year and 16,663 in the second; in the post-War period, however, the receipts in the two periods were reduced by 46 per cent. and 43 per cent. to 6,173 and 9,423 respectively. On the other hand, summer receipts (mainly grass-fed) increased, particularly in the third quarter, rising from 2,908 and 2,612 in the third and fourth quarters of 1909–13 to 3,273 and 3,319 respectively in 1925–9.

The effect of these changes is seen in the changed seasonal variation in prices. In the pre-War period prices reached a peak of about 4 per cent. above the average in June and July, and fell to about 3 per cent. below the average in November. In the post-War period the autumn drop was intensified to 7 per cent. below the average, while the peak, of 7 per cent. above average, was pushed forward to May. Prices are now, therefore, relatively higher in the spring, and lower in the autumn, than they were in the pre-War period.

Similar variations occur in wholesale and retail prices of British beef, and the accentuated autumn drop markedly affects the 'spread' between

[1] From the *Report of the Reorganization Commission for England and Wales* (as above).

TABLE 10. *Average Monthly Receipts of Fat Cattle at Norwich Market, 1909–13 and 1929–33, and Index Numbers of the Seasonal Variation in Fat-Cattle Prices in England and Wales*

	Receipts		Seasonal variation in prices	
	1909–13	*1929–33*	*1909–13*	*1925–9*
January	3,005	1,611	98·3	99·8
February	3,403	1,918	98·7	99·9
March	5,055	2,644	99·3	101·1
April	6,027	3,284	100·6	104·3
May	6,391	3,376	102·8	107·0
June	4,245	2,763	103·9	106·5
July	1,605	1,449	103·9	102·0
August	676	915	101·0	98·8
September	627	909	98·7	96·2
October	787	1,253	97·1	93·4
November	769	1,048	96·9	93·5
December	1,056	1,018	98·9	97·8
	33,646	22,188	100·0*	100·0*

* Average monthly price.

British and Argentine beef, the price of which shows comparatively little seasonal change. In 1924–6 the premium in favour of British beef averaged $3\frac{1}{4}d.$ per lb. in March and $2d.$ in September; by 1933 the March premium had been almost halved while the autumn drop in home prices had, in September, brought British beef within $\frac{1}{2}d.$ per lb. of the price of Argentine chilled (Table 11). These relative changes affect the relative demand for the two types of beef. It is unlikely, however, that the autumn price of British beef will fall below that of Argentine unless indeed there is a further decline in the quality of the home product.

TABLE 11. *Monthly Wholesale Prices and Spreads of British Fresh and Argentine Chilled Beef, 1924–6 and 1933*

	1924–6			1933		
	British	*Argentine Chilled, H.Q.*	*Difference*	*British*	*Argentine Chilled, H.Q.*	*Difference*
	d.	*d.*	*d.*	*d.*	*d.*	*d.*
January	$9\frac{3}{4}$	$6\frac{3}{4}$	3	$7\frac{3}{4}$	$6\frac{1}{4}$	$1\frac{1}{2}$
February	$9\frac{3}{4}$	$6\frac{3}{4}$	3	$7\frac{1}{2}$	6	$1\frac{1}{2}$
March	$9\frac{3}{4}$	$6\frac{1}{2}$	$3\frac{1}{4}$	$7\frac{1}{2}$	$5\frac{3}{4}$	$1\frac{3}{4}$
April	10	7	3	$7\frac{1}{2}$	6	$1\frac{1}{2}$
May	$10\frac{3}{8}$	$7\frac{3}{8}$	3	$7\frac{1}{4}$	$5\frac{3}{4}$	$1\frac{1}{2}$
June	$10\frac{3}{8}$	7	$3\frac{3}{8}$	$7\frac{1}{4}$	$5\frac{3}{4}$	$1\frac{1}{2}$
July	$10\frac{1}{8}$	$6\frac{7}{8}$	$3\frac{1}{4}$	7	$5\frac{1}{2}$	$1\frac{1}{2}$
August	$9\frac{3}{4}$	$7\frac{3}{8}$	$2\frac{3}{8}$	7	$6\frac{1}{4}$	$1\frac{3}{4}$
September	$9\frac{3}{8}$	$7\frac{3}{8}$	2	$6\frac{3}{4}$	$6\frac{1}{2}$	$0\frac{1}{2}$
October	9	$7\frac{3}{8}$	$1\frac{5}{8}$	$6\frac{3}{4}$	$6\frac{1}{4}$	$0\frac{1}{2}$
November	$8\frac{7}{8}$	$6\frac{7}{8}$	2	$6\frac{3}{4}$	$5\frac{3}{4}$	1
December	$9\frac{1}{8}$	$6\frac{3}{4}$	$2\frac{3}{8}$	7	6	1
Year	$9\frac{5}{8}$	7	$2\frac{5}{8}$	7	6	1

In looking to the future it is impossible to disregard the peculiar conditions of the last few years. On the one hand, we have seen the closing, against the beef-exporting countries, of markets which formerly absorbed a considerable proportion of their output. These supplies have been, as far as possible, diverted to Britain with the consequence that, in 1933, the United Kingdom took 80 per cent. of the world's total exports of beef and 50 per cent. of its exports of live cattle.

On the other hand, we have seen the adoption by this country of a policy the declared object of which is to give the home producer the first, and the overseas Empire producer the second, call on the home market, leaving only the balance to the foreigner. It was anticipated that the restriction of foreign supplies would raise the level of prices and would thus increase the return from home-produced and Empire beef. In fact, however, prices of British beef have failed to rise as a result of the restriction of chilled-beef imports. The next step has been to provide a temporary measure of relief to the home producer in the form of a direct subsidy, paid by the Exchequer; and the present intention is to make permanent provision for the continuance of such a subsidy by means of a levy on imports, the burden of which would fall either on the consumer or the foreign producer, or partly on each.

There is little doubt, then, that the future of the British beef market will depend in a considerable measure upon future political action, both at home and abroad, and is to that extent incalculable.

However, judging by past experience and assuming that the economic forces will continue to exert some influence, it is possible to make certain broad statements about the market for beef as a whole.

First, further expansion of the British market for beef and veal must depend on increased *per capita* consumption rather than on any considerable increase of population. Second, increased *per capita* consumption is dependent to a great extent on a higher level of industrial prosperity, for there is a close correlation between the spending power of consumers and the demand for beef and veal. Third, there is marked competition between beef and both mutton and pork. This has been largely responsible for the decline in beef consumption during the past few years, for there has been but little change in the total *per capita* consumption of meat. It is vital to the beef industry to discover whether the change-over from beef to other meats is due to a change of taste or to the relative cheapness of the competing meats. The evidence indicates that the relative cheapness of mutton has been a factor of very considerable importance, and it is not unreasonable to expect that a diminution of mutton and lamb supplies, accompanied by a rise in their prices, would result in a transference of demand back to beef. Undoubtedly the taste acquired recently for mutton and lamb will not immediately disappear, but it is difficult to believe that, in the long run, the relative price levels will not exert much of their old influence.

Examination of the long-term trends in prices and supplies shows that the markets for the different classes of beef are very different, and indeed suggests that fresh, chilled, and frozen beef may best be regarded as

three distinct commodities the demands for which are, however, rather closely interrelated.

Fresh beef normally enjoys a premium over the chilled product. There is, of course, little, and sometimes no difference between the price of inferior fresh and a better quality of chilled beef; but as between comparable grades fresh beef enjoys a marked premium. This premium reflects a general preference which is most marked in the country districts, small towns, and working-class districts, and least so in London and other large towns. The market for such beef is largely dependent upon general purchasing power. It has been relatively strong in recent years, prices for British beef having been maintained at a level considerably above that of imported beef. Should there be a general rise in sterling prices it is possible, as has happened in the past, that wage rates would rise less rapidly than prices. With a rise in general prices and a decline in real wages the cheaper imported beef would rise in price more rapidly than the better qualities of home-fed.

There are two other factors which are exerting an increasing influence on the market for home-produced beef. Firstly, the expansion of the dairy industry is undoubtedly lowering the average quality of British beef because, on the one hand, there is an increasing proportion of cow beef in the total output and, on the other, an increasing proportion of the available stores are bred from dairy rather than beef strains. This explains the fact that the over-all average price of British beef has in recent years been approaching that of cow and bull beef, and receding from the price level of the best quality. A large proportion of home-fed beef has thus been meeting much keener competition from the cheaper types, and notably from South American chilled. The upward trend in the price of chilled beef from 1923 till 1929, in the face of increasing supplies of chilled and in a period of declining prices for the home product was a clear indication of a swing-over in demand due probably, in the main, to a change in the relative qualities of the two articles. It is probable that the change has occurred largely among those classes of consumers for whom price is not the first consideration, and hence it will be the more difficult to induce them to return to the fresh product.

The second great change which is proceeding is in the seasonal distribution of the output, the concentration upon grass-feeding and autumn marketing bringing an increasingly heavy drop in prices during the last quarter of the calendar year. At that season first-quality British beef has recently been no more than a penny a pound dearer than Argentine chilled, while home-fed cow and bull beef has actually fallen below the level of chilled. There has been a corresponding relative rise in the price of home-fed beef towards the end of the winter-feeding period as a consequence, of course, of diminished supplies. It is not impossible, however, that this increasing disequilibrium of seasonal supplies may result in greater returns for the annual output as a whole. This depends on relative costs and on the extent to which the autumn market for home beef is expanded and the spring market is contracted in response to the changes in relative prices.

The future trends in the matters of average quality and of seasonal

output depend largely on factors external to the beef industry itself. On the one hand, higher returns from arable crops would probably stimulate winter fattening, which would result in a more even distribution of the output and relieve the glut of the autumn markets. On the other hand, lower returns for milk, which may prove inevitable, would doubtless result in a return from dairying to beef-production, with a consequent decline in the proportion of cow beef and an improvement in the average quality of the other classes.

Chilled beef is the medium-priced type. It is consumed partly by those who would prefer fresh beef but are unable to afford it, and partly by those who consider that its uniformity, &c., outweigh the advantage in flavour of the fresh beef. A reduction in the supplies, which may be a consequence of the very low returns recently obtained by producers in Argentina, would not necessarily result in greatly enhanced prices for British beef. Those who consume chilled beef from choice rather than from necessity might turn to the higher-priced home product, but they might transfer their demand mainly to other foods. Those who buy chilled beef because they cannot afford to have fresh would be unlikely to make the change. It is more probable that a reduction in supplies of chilled beef would cause an increased demand for frozen, and would thus assist the Dominion rather than the British producer.

Frozen beef is the cheapest type of meat. The demand for it is relatively inelastic and the market is a small one. During the period from the end of the War until the introduction of import regulation in 1932, supplies of frozen beef declined rapidly, being replaced by South American chilled and possibly to some extent by the poorer cuts and qualities of British beef. Demand for frozen beef is not one of choice but of necessity. If competing meats (such as mutton and pork) were dear, then a rise in chilled-beef prices might possibly increase the demand for the frozen product.

In conclusion, it is evident that the future expansion of the beef market in Great Britain depends primarily upon a maintenance and raising of the existing standards of living. This, in turn, may be held to depend upon industrial prosperity, and there appears to be general agreement that further substantial revival now awaits an expansion of the export rather than the domestic markets. If this is so, then it is almost inevitable that the purchasers of British manufactures, especially if these are Empire countries, will pay for them with agricultural produce. If, on the other hand, the tendency towards self-sufficiency is continued and imports are curtailed, a fall in standards of living is almost certain and one of the first markets to suffer will be that for home-produced beef.

(*Received March 5, 1935*)

THE SOILS OF SCOTLAND

Pt. I. INTRODUCTION: THE HIGHLANDS AND HEBRIDES

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WITH PLATE 12

I. *Introduction*

Although the total land surface of Scotland amounts to only 29,800 square miles, there is within that small area a considerable variety of soils. This is mainly due to the contrasts in configuration, the varied geology, and the differences in climate.

The general trend of the geological formations is from south-west to north-east, and the country as a whole is hilly and mountainous. There are two main masses of hills—the Highlands and the Southern Uplands. The former group occupies the major part of northern and western Scotland, and the latter occupies the southern belt just north of the English border. Between them is a tectonic trough about 50 miles wide, stretching from coast to coast in a north-easterly and south-westerly direction. This great central plain, together with a fairly broad shelf along the north-east coast, provides most of the agricultural land and supports the great bulk of the population.

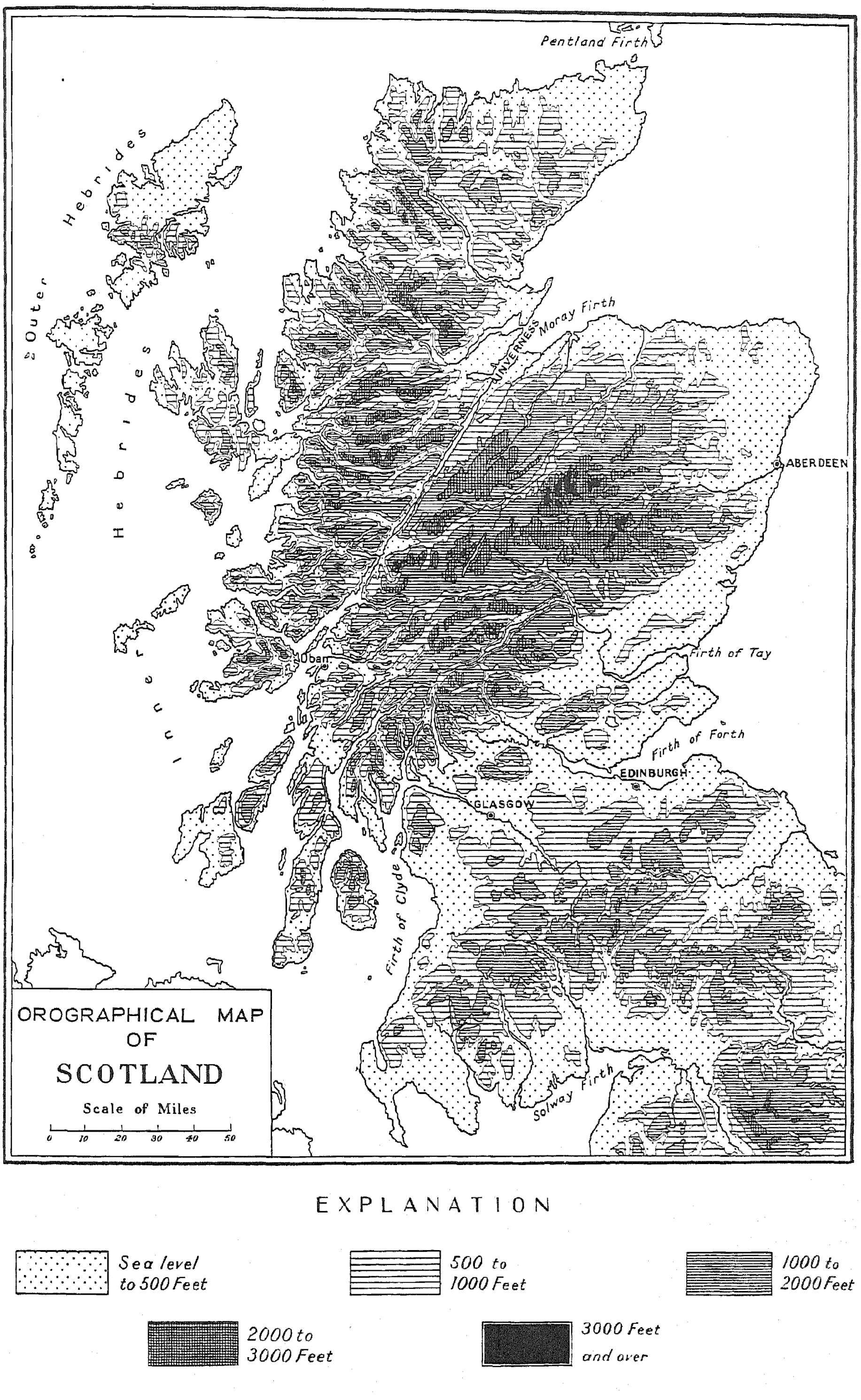
About two-thirds of the total area of Scotland lies at a height of more than 1,000 ft. (305 m.) and approximately half the country is classed in the ordnance survey as 'mountain and heath' (see orographical map).

Climate.—The climate of Scotland is cool and humid. The average evaporation from a free water surface is less than 16 in. (406 mm.) in a year, and the rainfall ranges from about 25 in. (625 mm.) at one or two places on the east coast, to well over 100 in. (2,540 mm.) on the highest mountains of the west. The precipitation is therefore much greater than the evaporation. According to H. R. Mill, two-thirds of the surface of Scotland has an annual rainfall of over 40 in. (1,016 mm.) and only one-fifteenth a rainfall of less than 30 in. (762 mm.). The prevailing winds are from the south-west, and the mountainous region on the west coast is consequently the most rainy portion of Scotland. The distribution of rainfall throughout the year is fairly uniform, and the average number of rain-days in a year reaches a maximum of 250 in the north-west compared with 175 in the English Plain.

The mean temperature ranges from about 4·4° C. in January to 15·6° C. in July, and the daily range is greater on the east coast than on the west coast. At altitudes of over 1,000 ft. (305 m.), the winter climate is fairly severe, but the extremes of temperature in both summer and winter for the country as a whole are much less than at places of corresponding latitudes on the mainland of Europe.

The number of hours of sunshine varies throughout the country from about 1,200 to 1,300.

Geology.—For a small country there is great geological diversity (see



OROGRAPHICAL MAP
OF
SCOTLAND
Scale of Miles
0 10 20 30 40 50
Pentland Firth
Outer Hebrides
Hebrides
Inner
Moray Firth
INVERNESS
ABERDEEN
Oban
Firth of Tay
Firth of Forth
EDINBURGH
GLASGOW
Firth of Clyde
Solway Firth
EXPLANATION
Sea level to 500 Feet
500 to 1000 Feet
1000 to 2000 Feet
2000 to 3000 Feet
3000 Feet and over

geological map). The Southern Uplands are composed of Ordovician and Silurian formations, the Central Plain of Old Red Sandstone and Carboniferous, and the Highlands chiefly of metamorphic and igneous rocks. The materials as a whole are predominantly siliceous, and limestone is scarce in most regions.

The whole country has been glaciated, and most of the land to an altitude of 1,000 ft. (305 m.), and in many places to 2,000 ft. (610 m.), is covered with glacial drift. The drift varies in texture from a clay with boulders to a coarse sand and gravel. Where the drift is deep the matrix may consist of materials from several rock types, but where it is thin it is usually closely related in mineralogical composition to the underlying formation.

Agriculture.—The agriculture of the country is more or less concentrated in the Central Valley and the north-eastern region. Of a total area of 19 million acres in Scotland, just over 4½ million acres are under crops and grass, of which about 1½ million acres are permanent grass; forests account for nearly a million acres, deer forests for 3½ million acres, and the remainder, amounting to about half the total area of the country, consists of mountains and heath-land used as rough grazing.

The official returns of the Department of Agriculture for Scotland and the Ministry of Agriculture give the average acreage and the average estimated yield per acre for the principal crops (1923–32) as follows:

	Average acreage	*Average estimated yield (cwt. per acre)*	
		Scotland	*England*
Total acreage crops and grass	4,673,290	..	..
Permanent grass	1,516,031	31·8*	21·0*
Rotation grass	1,505,563	33·0*	29·3*
Oats	901,812	15·4	15·6
Barley	117,864	17·9	15·9
Wheat	54,219	21·2	17·4
Potatoes	139,526	132·0	126·0
Turnips	381,051	332·0	252·0

* Yields for permanent and rotation grass refer to acreage mown for hay.

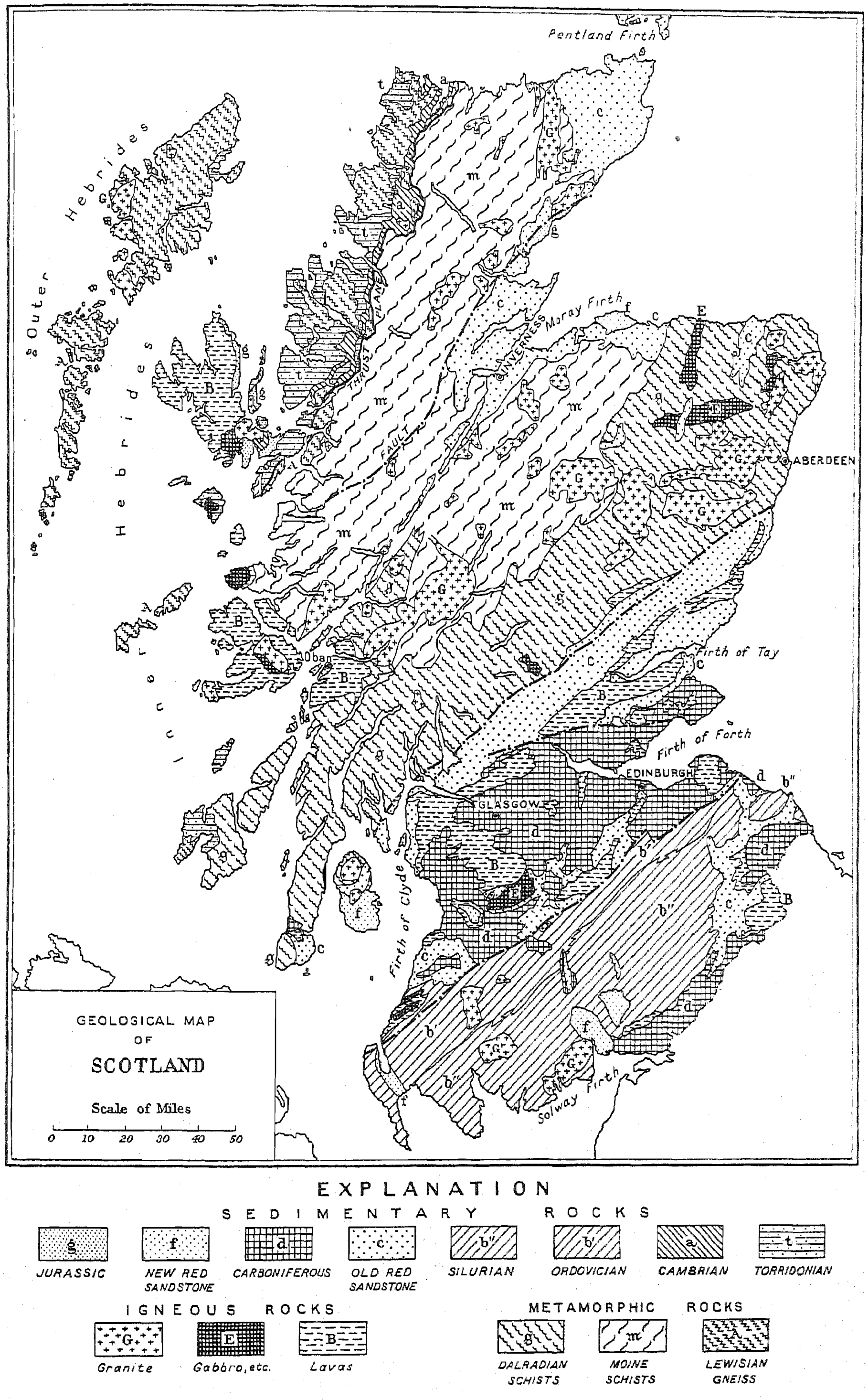
The other crops, including sugar-beet, mangolds, rye, beans, peas, small fruit, and orchards, together had a total acreage of about 57,000.

There has been a decline of a quarter of a million acres in the area under crops and grass in the past 40 years, and in recent years much arable land has been laid down to permanent grass.

In 1933 the dairy cattle numbered 483,909, other cattle 809,728, horses 149,483, sheep 7,811,144, and pigs 167,028.

With regard to size of holdings, the total number in 1933 was 75,642, of which 50,402 were from 1 to 50 acres, and 25,240 over 50 acres in extent. About 18,000 were owned by the occupiers.

A useful collection of statistics and maps showing the distribution of the various crops and classes of stock is to be found in H. J. Wood's *Agricultural Atlas of Scotland*.



Pentland Firth
Outer Hebrides
Inner Hebrides
Moray Firth
INVERNESS
THRUST PLANE
FAULT
ABERDEEN
Oban
Firth of Tay
Firth of Forth
EDINBURGH
GLASGOW
Firth of Clyde
Solway Firth
GEOLOGICAL MAP OF SCOTLAND
Scale of Miles
0 10 20 30 40 50
EXPLANATION
SEDIMENTARY ROCKS
JURASSIC
NEW RED SANDSTONE
CARBONIFEROUS
OLD RED SANDSTONE
SILURIAN
ORDOVICIAN
CAMBRIAN
TORRIDONIAN
IGNEOUS ROCKS
Granite
Gabbro, etc.
Lavas
METAMORPHIC ROCKS
DALRADIAN SCHISTS
MOINE SCHISTS
LEWISIAN GNEISS

Soils.—The main soil groups are as follows:

- Podsolic soils.
- Gley podsolic soils.
- Gley (water-logged) soils and deep peat.
- Brown soils.
- Soils with undeveloped profiles (skeletal soils, creep soils, recent alluvial soils, &c.).

(i) *Podsolic soils.* Three main subdivisions of the podsolic group may be recognized; slightly, moderately, and strongly podsolized soils, the degree of podsolization depending chiefly on texture, composition of the parent material, climate, and vegetation.

(ii) *Gley podsolic soils.* These show indications of impeded drainage by the occurrence of a gley horizon or gley spots. These layers or spots are greenish-grey or bluish in colour, with rusty spots, streaks, and sometimes concretions. The rusty mottling is due to the deposition of hydrated ferric oxide, and is brought about by the alternation of oxidizing and reducing conditions. The water-logging may be due to high ground-water table, or to the holding up of surface-water through the impermeability of the B or C horizons. The gley horizons may therefore occur in various parts of the profile. Two sub-groups are recognized, gley podsolic soils and peat gley podsolic soils, the latter having a peat layer on the surface.

(iii) *Gley soils.* In addition to the gley podsolic group, gley soils occur in which the podsolic characters are absent, and the gley horizon extends to the surface, or to the peat layer which often covers the surface. Three subdivisions of this group are found, gley soils, peat gley soils, and deep peat.

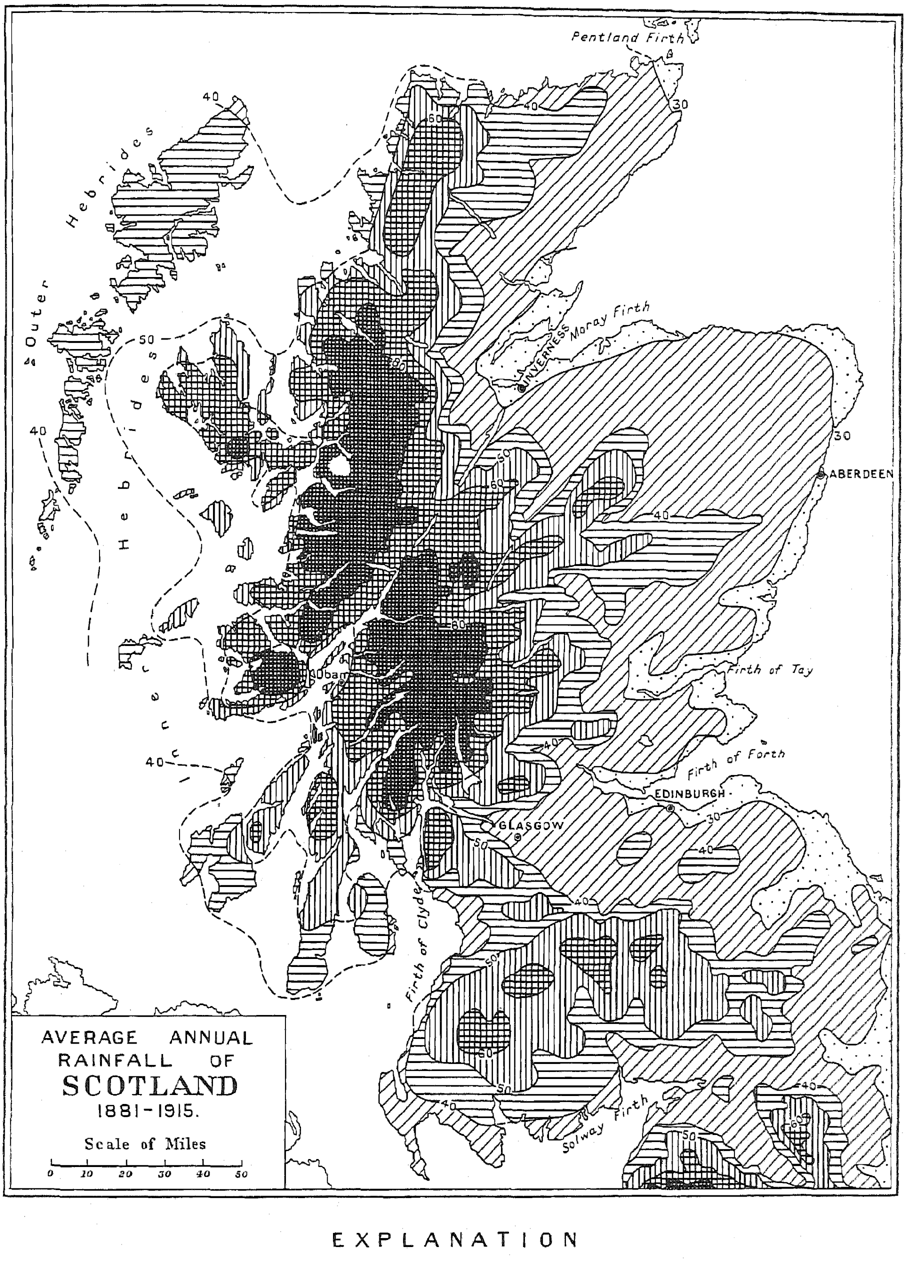
(iv) *Brown soils.* This term is used provisionally to designate a rather ill-defined group of soils found in various parts of Scotland. Morphologically these soils differ from podsols in having a more or less uniform profile without a surface covering of raw humus, and with no evidence of a zone of accumulation. They appear to be associated with parent materials with a high content of bases, and, at any rate in the field, resemble the brown earths described in various countries. A chemical examination, however, showed that these soils have undergone a certain amount of leaching of bases from the surface layers, and that in some cases a slight translocation of sesquioxides had occurred.

In a publication[1] dealing with the soils of the Crimean National Park, Antipov-Karataiev and Prasolov describe what seem to be similar soils and term them brown soils. They occur on igneous rocks, and have a slight accumulation of sesquioxides in the middle horizons, but morphologically do not in any way resemble podsols.

In the cultivated areas in Scotland, brown soils occur which may be due to the influence of man. The writer has already pointed out[2] that draining, liming, manuring, cultivation, and cropping may bring about such marked changes in the profile that many soils which belonged originally to podsolized or gley types now resemble brown earths.

[1] *Trans. Dokuchaiev Soil Inst.*, 1932, vii, 65 ff.

[2] Preface to the English translation of text accompanying First Soil Map of Europe.



EXPLANATION

Scale of Rainfall in Inches.

Under 30 | 30 to 40 | 40 to 50
50 to 60 | 60 to 80 | Over 80

Reproduced from Plate I of the Royal Meteorological Society's Rainfall Atlas of the British Isles, by kind permission of the Controller of H.M. Stationery Office.

These Scottish brown soils under natural conditions may be approaching the slightly podsolized group, but for practical purposes it seems desirable to separate them from the podsol group. Insufficient work has been done, however, to make it possible to define them accurately.

(v) *Soils with undeveloped profiles.* Probably many of the soils in the groups already mentioned are immature, but in this group the immaturity is due to changes in the surface material which counteract or mask profile-formation. Three sub-groups are recognized:

(*a*) Skeletal soils in which the material is chiefly rock debris with fine material in the interstices.
(*b*) Creep soils in which material is carried down slopes and where consequently there is constant change.
(*c*) Recent alluvial soils in which deposition and redeposition of material is still going on.

In addition to the groups described, there are many areas where truncated or eroded profiles occur. The surface soil, often the A horizon, is removed through down-washing, and the layer below exposed and subjected to fresh weathering. In other cases the removed surface is replaced by fresh downwash material.

There are four main geographical divisions in Scotland, and it is convenient to adopt the same divisions in dealing with the soils, viz.: the Highlands, the North-eastern Region, the Central Valley, and the Southern Uplands.

II. *The Highlands and Hebrides*

The Highlands constitute an elevated plateau of bold relief intersected by deep valleys, and occupy most of the northern half of Scotland except the broad shelf of low country fringing the east coast. On account of the mountainous character and high altitude of most of the area, agriculture is poorly developed. The hill slopes are used for sheep-grazing, deer forests, and forestry, but there is a certain amount of cultivation in the glens.

The rainfall is high, much of the western part of the area having an annual rainfall of over 60 in. (1,524 mm.).

The rocks are mainly crystalline, consisting of coarse gneisses, schists (mainly siliceous), Torridonian sandstone, Cambrian limestones, grits, and quartzites. There are also areas of intrusive igneous rocks, both acid and basic. Lewisian gneisses and Highland schists cover the most extensive area. In the north-western Highlands there are extensive areas where the land surface is covered with acid peat, and the dominant vegetation is *Scirpus caespitosus*. The central and eastern Highlands, especially the eastern portion, has a somewhat drier climate, the peat is thinner, and the dominant vegetation is *Calluna vulgaris* and *Vaccinium Myrtillus*. Probably extensive forests occurred at one time on the slopes of many of the mountains, but widespread deforestation has occurred. The chief indigenous trees are Scots pine, oak, birch, alder, ash, and elm. Larch was first introduced into Scotland in 1738, and is now grown extensively; spruce and beech are also introduced trees which

are now abundant, and in more recent times Douglas fir and Sitka spruce have been planted extensively.

In the central Highlands (N. Perthshire), according to R. Smith,[1] the upper limits for oak are 900–1,000 ft. (274–305 m.), for birch 1,500–2,000 ft. (457–610 m.), for larch 1,300–1,800 ft. (396–594 m.), and for Scots pine 1,500–1,800 ft. (457–549 m.). In the same region, *Erica cinerea* and *E. Tetralix* cease at an altitude of 2,200 ft. (670 m.), *Calluna vulgaris* ceases at 3,100 ft. (945 m.), and *Vaccinium Myrtillus* at 3,600 ft. (1,096 m.).

Peat. Because of the widespread occurrence of peat in Scotland, and particularly in this region, it is desirable to deal with it separately before giving an account of the soils. The Forestry Commission has recently published a bulletin on 'Scottish moorland in relation to tree growth', by G. K. Fraser,[2] and the following account is based largely on his work.

Most of the peat-land in Scotland may be classed as Climatic moor. Fraser prefers this term to Alpine moor, as it occurs extensively in Britain at low elevations as well as in the mountains. It is regional in distribution, and associated with high rainfall and low summer temperature. The *Scirpus* moor of the north-west Highlands, the *Calluna* moor (or *Calluna-Eriophorum*) of the north-central Highlands, and the *Molinia* moor of the Southern Uplands belong to this class.

The much less extensive peat-land which is due to bad surface drainage, and which forms in hollows or depressions, is termed by Fraser 'Basin Moor'. It is local or topographical in distribution, and includes low moor, transition moor, and high moor. In Scotland, acid peat-mosses of the basin type occur in various parts of the country.

Fraser groups the Scottish peats morphologically in the following way:

A. 'Pseudo-fibrous peat'—soft and plastic, rigidity and tenacity lost, fibrous in appearance only. (*a*) Var. 'Cheesy peat'—rigidity partly maintained under intermittent aeration.

B. 'Fibrous peat'—tough and flexible, composed of scarcely altered remains of plants.

C. 'Amorphous peat'—showing no recognizable plant tissues.

Fraser gives analyses of samples from various peat types in the west of Scotland. Most of the samples are from Inverliver, near Loch Awe, an area typical of the western Scottish moorland region. The annual rainfall is about 80 in. (2,032 mm.), the altitude from 300 to 800 ft. (91–244 mm.) above sea-level, and the underlying rocks epidiorite and metamorphic grits.

A. *Pseudo-fibrous peat.*—This is the most extensive type in the Highlands, and according to Fraser it is the climax peat of the western Scottish region. He describes several varieties including:

1. *Scirpus high-moor peat.* This consists of a thin surface turf in which the plant-remains are little altered, and the roots of living plants occur. At a depth of a few inches the peat is soft and plastic, and if squeezed in the hand oozes out between the fingers. Traces of structure, chiefly

[1] R. Smith, *Scot. Geog. Mag.*, 1900, **16**, 465.

[2] *Forestry Commission Bulletin*, No. 15 (1933).

TABLE 1. *The Ash of Typical Peats and its Analysis*

(Expressed as a percentage of weight of peat dried at 98–100° C.)

Type of Vegetation and peat	Total	Ash-content: In-soluble silicates	Ash-content: Sol. in HCl	Analysis of soluble ash: Fe_2O_3 and Al_2O_3	CaO	MgO	K_2O	P_2O_5
Deep *Scirpus*	5·69	4·20	1·49	1·04	0·17	0·09	0·04	0·06
Scirpus-Calluna	11·54	7·14	4·40	3·21	0·48	0·43	0·09	0·07
Moraine *Calluna*	6·98	5·63	1·35	0·56	0·46	0·11	0·03	0·05
Eriophorum vaginatum types	6·57	3·66	2·85	1·83	0·52	0·28	0·06	0·06
Juncus articulatus dominant	13·72	8·15	5·57	2·81	1·46	0·21	0·09	0·15
Molinia flushes	21·54	13·27	8·30	10·65	0·75	0·10	0·10	0·09

the tubular remains of *Scirpus* roots, occur, but these remains are soft and their structure is readily destroyed. Animals are apt to sink in this type of peat where the surface turf is broken or removed. The freshly cut peat is yellowish brown, but when exposed to air for some time a dark brown or blackish somewhat amorphous crust is formed on the surface.

The pH of this peat ranges from 3·5 to 4·5, and, as will be seen from Table 1, the contents of calcium, potassium, and phosphoric acid are all very low.

The dominant vegetation in typical areas is *Scirpus caespitosus*, which during the growing season forms a green cover over the ground. This accounts for the green appearance of much of the western Highlands in contrast with the brownish appearance of the eastern Highlands, where *Calluna* is dominant.

Even in typical *Scirpus* high moor, *Calluna* of stunted growth is usually present in scattered patches. Amongst other plants which occur are *Narthecium ossifragum*, *Potentilla tormentilla*, *Erica Tetralix*, and *Eriophorum polystachion*. The chief mosses are the smaller *Sphagnums* and various other moorland and heath mosses, such as species of *Hypnum*, *Brachythecium*, &c.

Fraser describes a variety of *Scirpus* high-moor peat which he terms 'cheesy' peat. It is a shallow type rarely exceeding a foot in depth, and is similar in character to the crust which forms on the surface when the yellowish-brown peat just described is exposed to the air. The fibres are tough, and the structureless material is dark brown and has a curdy texture somewhat like stiff cheese. It can be broken into pieces even when wet, and has a much lower water-retaining power than typical pseudo-fibrous peat.

The vegetation of this variety contains more *Calluna* than the main type; in fact, it may be the dominant plant, although *Scirpus* is still abundant.

2. *Basin type*. Pseudo-fibrous peat also forms over fibrous peat in hollows where water accumulates, and this type occurs not only in the western Highlands, but also in the east, and in other parts of the country. The vegetation is of the *Scirpus-Calluna* type.

B. *Fibrous peat.*—Fibrous peat varies in appearance and composition according to the material from which it is derived, but the plant-remains are much less decomposed and altered than in pseudo-fibrous peat. The surface layer is usually tough and difficult to cut. The lower layers can be sliced easily with a spade, but, unlike pseudo-fibrous peat, the material does not exude through the fingers when compressed in the hand, and after compression the material expands to something like its original size. On drying, it becomes open and porous and does not show the marked shrinkage of pseudo-fibrous peat. The colour is usually brown, and does not alter much on drying. Peats of this class occur extensively in the Highlands, particularly in the eastern part, and at any rate in the western region Fraser regards them as a transition stage to pseudo-fibrous peat.

There are various subdivisions in the fibrous-peat group:

1. *Calluna, and mixed Calluna (or Calluna-Eriophorum) Moor.* This type occurs extensively in the eastern and central Highlands, where the summer is somewhat drier and the evaporation higher than in the west.
2. *Flush types.* These occur typically where there is slow percolation of water low in bases.
3. *Basin types.* These are local in distribution and consist of mixtures of sedge peat from such plants as *Carex ampullacea* with *Sphagnum*, and areas of purer *Sphagnum* peat.

C. *Amorphous peat.*—There are various types, the most important being rush peat and *Molinia* peat. They are associated particularly with conditions where the content of bases in the water is high.

Utilization of peat-land in the Highlands and Hebrides.—Most of the peat-land is used as rough sheep-grazing or deer-forest, and receives little attention. Regular heather-burning is practised by most sheep farmers, and here and there a little draining is done by means of shallow open drains.

Small areas of peat-land are cultivated by crofters. In the island of Lewis, for example, with a total area of 683 square miles (mostly peat-covered), only 18 square miles are under cultivation, and a large part of this is on the limited mineral soil.

There is a desire for more agricultural holdings on the part of the people in the Highlands, and the Government is not averse to the creation of such holdings if a satisfactory and economic means of reclaiming the peat-land of these regions can be found. The problem is meantime being studied on the Macaulay Demonstration Farm in Lewis. An area of very wet moorland of the pseudo-fibrous (*Scirpus*) type has been drained, treated with shell sand, manured, and cultivated. Satisfactory pasture with abundant wild white clover has been established, and hay, oats, potatoes, and silage mixtures grown successfully. Difficulties have been encountered with regard to drainage, and details as to drainage methods have still to be worked out. The preliminary results already obtained, however, indicate that there are possibilities of the agricultural utilization of peat-land, even of difficult types such as *Scirpus*.

On the forestry side, the Forestry Commission has been carrying out fairly extensive afforestation in the Highlands, and also an experimental programme at Auchterawe, near Fort Augustus, Inverness-shire, and other places. It is still too soon to draw conclusions, but the chief limiting factor appears to be lack of air in the peat. The worst peat from a forestry point of view appears to be the pseudo-fibrous (*Scirpus*) type, and the problem of its satisfactory drainage has not yet been solved. According to Fraser, the planting of doubtful peat ground may be successfully carried out after thorough drainage by turf-planting, using basic slag as a peat-improving manure, but on bad peat-ground more drastic measures are required, and the surface conditions must be altered over the area as a whole. This may be done in one or other of the following ways: (*a*) by the establishment of a less exacting soil-improving cover species, of which none of those tried so far has proved satisfactory, (*b*) by extending the areas already influenced by flush-water, with or without the assistance of manure, and (*c*) by proper mechanical cultivation of the surface, combined with drainage and manuring.

Soils.—The main soil groups[1] found in this region are:

1. Podsolic soils.
2. Gley podsolic soils.
3. Gley soils and deep peat.
4. Soils with undeveloped profiles.

1. *Podsolic soils*.—These soils occur especially on moraines and slopes where the parent material is rather coarse in texture, allowing free drainage. On the finer-textured parent materials in this region of high rainfall, gley podsolic and gley soils usually form instead of podsolic soils. The degree of podsolization in this as in other regions in Scotland is largely influenced by the texture and the content of bases of the parent material.

The following example of a medium podsolized soil of the podsol group is taken from Inchnacardoch, near Fort Augustus, Inverness-shire. The profile (Plate 12, *a*), which is on flattish ground, is from fluvio-glacial material overlying quartzose schists; the average rainfall is 44 in. (1,117 mm.) per annum, and the altitude about 120 ft. (36·5 m.) above sea-level. The present vegetation is mainly *Calluna vulgaris* with some *Scirpus caespitosus* and various mosses. There is evidence of frequent heather-burning.

(1) 0–5 cm.	Dark brown to black *Calluna* turf, very tough and fibrous, with occasional stones; depth variable.
(2) 5–18 cm.	Dark olive-brown gritty sand, dries to dark grey; many roots, stones, and pebbles, varies somewhat in depth.
(3) 18–21 cm.	Dark rusty brown gritty sand; roots frequent. A thin hard pan occurs at about 18 cm.
(4) 21–45 cm.	Rusty brown gritty sand; pebbles abundant and in places forming layers; roots infrequent.
(5) 45–130 cm.	Yellowish-fawn gritty sand; loose and friable; many pebbles and stones; roots rare.

[1] There is some evidence that the brown-soil group also occurs, but it has not yet been studied in this region.

TABLE 2. *Analyses of a Medium Podsolized Soil. Inchnacardoch, Inverness-shire*

	(1)	(2)	(3)	(4)	(5)
Depth	0–5 cm.	5–18 cm.	18–21 cm.	21–45 cm.	45–130 cm.
pH	4·71	4·84	5·05	5·51	5·85
Loss on ignition	43·51	11·58	7·98	3·05	0·85
*Clay fraction SiO_2/R_2O_3	..	1·22	0·78	0·78	1·00
,, SiO_2/Fe_2O_3	..	31·61	2·07	2·21	4·25
,, SiO_2/Al_2O_3	..	1·27	1·25	1·21	1·35

* The 'clay' fraction was prepared using a time-depth ratio of 8·6 cm./24 hours.

The above analyses show that marked podsolization has occurred, but the somewhat high content of organic matter in layer 2, due possibly to repeated heather-burning, masks the grey colour when the soil is seen wet in the field.

2. *Gley podsolic soils.*—This group, with its two subdivisions, gley podsolic and peat-gley podsolic soils, occurs very extensively in the Highlands. An example of a gley podsolic soil is taken from a Scots pine wood at Achnashellach, Ross-shire. The parent material is morainic drift overlying granulitic schists, and the average annual rainfall is about 84 in. (2,134 mm.). The vegetation consists mainly of *Pinus sylvestris*, *Pyrus aucuparia*, and *Vaccinium Myrtillus*. Various mosses and rushes are also present.

(1) 0–20 cm. Turf of decaying needles, leaves, roots, &c.; dark brown at surface, becoming blacker and more decomposed with increasing depth.

(2) 20–25 cm. Light grey stony gritty sand, almost white when dry; loose, friable, and structureless; roots common.

(3) 25–50 cm. Rusty brown to blackish brown sandy loam; stony, loose, and structureless; roots common.

(4) 50–80 cm. Olive-grey to blackish stony sandy loam, loose and structureless; roots frequent.

(5) 80–85 cm. Rusty brown, strongly cemented, gritty sand with thin hard pan at 80 cm.; stony and structureless; roots stop at this layer.

(6) 85–100 cm. Fawn, stony gritty sand with occasional black spots; structureless; roots absent.

In many places the first and second layers are thicker and are followed by the olive-grey fourth layer, the third layer being absent.

TABLE 3. *Analyses of a Gley Podsolic Soil, Achnashellach, Ross-shire*

	(1)	(2)	(3)	(4)	(5)	(6)
Depth	0–20 cm.	20–5 cm.	25–50 cm.	50–80 cm.	80–5 cm.	85–100 cm.
pH	4·01	4·15	5·15	5·04	5·30	5·39
Loss on ignition	97·34	0·80	10·48	9·32	1·89	0·96
Clay fraction SiO_2/R_2O_3	..	2·16	0·46	0·72	0·42	0·65
,, SiO_2/Fe_2O_3	..	10·94	1·05	4·85	1·32	1·75
,, SiO_2/Al_2O_3	..	2·69	0·79	0·85	0·61	1·03

The figures show strong podsolization in the upper layers and possibly a secondary leaching in layer (4), which has given rise to an abnormal distribution of the iron, and may be due to the influence of ground-water. The distribution of the alumina appears to be quite normal.

An example of a peat-gley podsolic soil is taken from the Golden Valley, Achnashellach, Ross-shire, and the parent material is similar to that of the previous profile. The vegetation consists of *Molinia caerulea*, *Scirpus caespitosus*, *Erica Tetralix*, *E. cinerea*, *Calluna vulgaris*, and various mosses; *Narthecium ossifragum* and *Potentilla Tormentilla* also occur.

(1) 0–20 cm.	Blackish peat, fibrous but fairly well decomposed; thicker in places.
(2) 20–30 cm.	Medium grey, sandy layer passing into light grey with increasing depth; stony and gritty; roots frequent.
(3) 30–40 cm.	Olive-grey to blackish-brown, strongly cemented, stony, gritty sand; few roots pass this layer.
(4) 40–50 cm.	Compact stony, gritty sand, mottled fawn and rusty brown; thin iron pan at 40 cm.; roots occur.
(5) 50–100 cm.	Light fawn, stony, gritty fine sand; fairly compact; roots occur in upper 10 cm.

TABLE 4. *Analyses of a Peat-gley Podsolic Soil, Golden Valley, Achnashellach, Ross-shire*

	(1)	(2)	(3)	(4)	(5)
Depth	0–20 cm.	20–30 cm.	30–40 cm.	40–50 cm.	50–100 cm.
pH	4·35	4·73	4·99	5·19	5·41
Loss on ignition	93·35	1·08	4·51	3·56	0·69
Clay fraction SiO_2/R_2O_3	..	1·62	1·21	0·44	1·35
,, SiO_2/Fe_2O_3	..	6·24	7·20	1·14	7·73
,, SiO_2/Al_2O_3	..	2·19	1·45	0·70	1·64

This profile differs from the preceding in the occurrence of peat instead of raw humus in the surface layer, in the occurrence of the olive-grey horizon nearer the surface, and in the absence of a rusty-brown layer above the olive-grey.

From the figures in Table 4 it would appear that marked leaching of the second and third layers has taken place, and the cementation in layer (3) does not appear to be due to iron, but to humic material.

3. *Gley soils and deep peat.*—This group of water-logged soils occurs very extensively in the Highlands and Hebrides. It is convenient to divide it into (1) gley soils, which have no peat on the surface, (2) peat-gley soils, in which the surface layer of peat is not thick enough to prevent the roots of surface vegetation from reaching the mineral soil below, and (3) deep peat.

The following description of a peat-gley soil is that of a profile at an altitude of 700 ft. (213 m.) on a hill slope at Achnashellach. The

average annual rainfall is about 84 in. (2,134 mm.), and the parent material is morainic drift over granulitic schists. The vegetation consists of *Scirpus caespitosus*, *Erica cinerea*, *E. Tetralix*, *Calluna vulgaris*, *Juncus squarrosus*, mosses, &c.

(1) 0–50 cm. Black fibrous greasy peat with brownish tinge; lower 20 cm. contains large stones.
(2) 50–55 cm. Sandy loam, with rusty staining, especially on stones; stony and structureless; indurated; indications of hard pan; occasional roots.
(3) 55–70 cm. Fawn, stony sandy loam; occasional boulders; structureless; compact but not cemented; slight rusty staining in places; roots rare.
(4) 70–100 cm. Similar to layer above, but greyish in colour.

TABLE 5. *Analyses of a Peat-gley Soil on a Hill slope, Achnashellach, Ross-shire*

	(1)	(2)	(3)	(4)
Depth	0–50 cm.	50–5 cm.	55–70 cm.	70–100 cm.
pH	4·43	4·91	5·02	5·19
Loss on ignition	96·18	2·55	1·85	1·33
Clay fraction SiO_2/R_2O_3	..	0·85	1·17	2·19
,, SiO_2/Fe_2O_3	..	2·81	7·03	6·03
,, SiO_2/Al_2O_3	..	1·22	1·41	3·43

The high content of iron in layer (2) may be accounted for partly by the removal of silica, which has been found to be associated with gleying, and partly by the iron being brought up by rises in the ground-water level.

A second example of a peat-gley soil is from a wet hollow at Inchnacardoch, Fort Augustus, Inverness-shire. The altitude is about 900 ft. (274 m.), the rainfall 44 in. (1,118 mm.), and the parent material is drift over quartzose schists. The vegetation consists of *Myrica Gale*, *Molinia caerulea*, *Erica Tetralix*, *Calluna vulgaris*, and *Narthecium ossifragum*.

(1) 0–45 cm. Brownish-black fibrous sodden peat.
(2) 45–70 cm. Olive-grey gritty loam; very stony and not compact; roots penetrate top 10 cm.

This profile differs from the preceding in being permanently, instead of temporarily, waterlogged, and there is consequently no oxidation going on. The clay-fraction figures for layer (2) were:

$$SiO_2/R_2O_3 = 1{\cdot}49. \quad SiO_2/Fe_2O_3 = 11{\cdot}29. \quad SiO_2/Al_2O_3 = 1{\cdot}71.$$

4. *Soils with undeveloped profiles.*

(*a*) *Skeletal soils.* These occur extensively in the Highlands on the hill slopes.
(*b*) *Creep soils.* Common on the hill slopes and at the foot of hills.
(*c*) *Recent alluvial soils.* Although not extensive in any one place, the total area covered by these soils in the numerous glens is considerable (Plate 12, *b*).

An example of a creep soil is taken from a hill slope at Lael Forest, Braemore, near Loch Broom, Ross-shire. The average annual rainfall is about 60 in. (1,524 m.) and the altitude is 100 ft. (30·5 m.). The parent rock is biotite schist.

The vegetation consists of *Pteris aquilina*, *Erica cinerea*, various grasses, mosses, &c.

(1) 0–15 cm. (variable depth). Brown, light loam with soft crumb structure; small stones common; roots abundant.

(2) 15–120 cm. Light brown light loam between boulders; loose and friable; stones abundant; roots occur to depth of 115 cm.

All the examples given above are from uncultivated ground, since most of the land in the Highlands and Hebrides has not been cultivated. The outstanding features of these Highland soils are the marked leaching and the effects of water-logging. Comparatively little detailed work has so far been carried out on these soils, but recently they have been studied by A. Muir, to whom I am indebted for descriptions of profiles. I desire also to express indebtedness to H.M. Geological Survey and to the Air Ministry for geological and rainfall maps, and to the Department of Agriculture for Scotland for statistics relating to agriculture.

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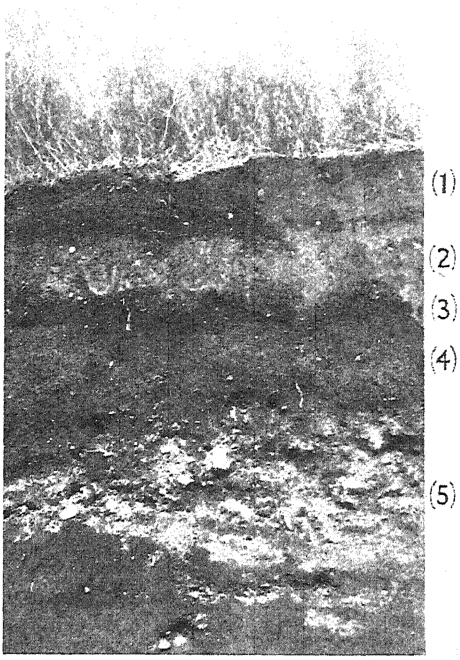
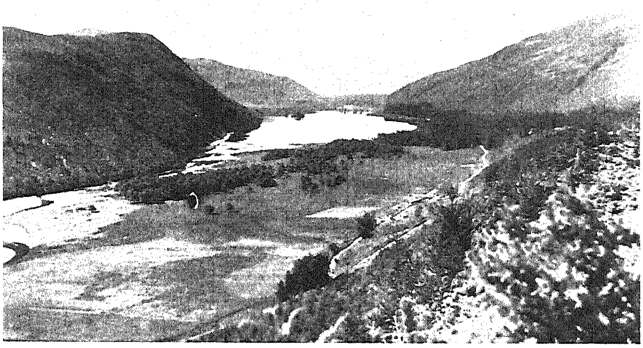


a. MEDIUM-PODSOLIZED SOIL



b. GLEN CARRON, ROSS-SHIRE

MIXED CROPPING IN PRIMITIVE AGRICULTURE

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IN previous publications [1, 2, 3] the author has stressed the importance to non-leguminous plants of leguminous plants growing in mixture with them. There is a considerable amount of evidence, much of which has been reviewed in [2], that in mixed cropping the leguminous component of a mixture can act as provider of nitrogen for the non-legume. The author [2] has already mentioned the practice common near Cawnpore of growing gram (*Cicer arietinum*) **P**[1] and wheat together. Dr. H. H. Mann recently directed[2] the author's attention to the fact that the culture of mixed crops is much more widespread than would be inferred from that isolated example.

Of *bajri* (*Pennisetum typhoideum*) in the Bombay Deccan, Mann [5] wrote:

> Its real importance would be better understood if the area under the so-called *bajri* mixture were taken. The *bajri* mixture contains several leguminous crops, and hence can be grown year after year without affecting the fertility of the land to any great extent. As a result there is little of ordinary rotation practised. . . . It [*bajri*] is never sown alone, but always mixed with one or more pulses and several other seeds. . . . The special feature of the *bajri* mixture in this village is the very large number of [varieties of] seeds which are mixed with the *bajri* before sowing. . . . The seeds sown are stated to vary according to the soil. . . . The mixture is sown with a three-coulter drill, and at the same time a fourth row is sown either with *tur* [*Cajanus indicus* **P**] or *kulthi* [*Dolichos biflorus* **P**] according to the nature of the soil.

Mann added a table showing the proportions of seed of ten species in eight mixtures analysed after sampling at time of sowing. No sample contained fewer than four species in addition to that sown in the fourth row.

Mann gave sociological and agricultural reasons to explain this custom of growing mixtures rather than single crops.

> None of the pulses, the oil-seeds, or the other constituents of the mixture are ever sown as independent crops. . . . In practice, it is a fact that whenever the crop of *bajri* is good, the crop of pulses is poor [and so on]. The land is mostly very poor, and it is hence not possible to follow a system of rotation. Hence, the mixture, which answers, in part at any rate, the same purpose, is resorted to.

It is noteworthy that the poorer the land, the smaller the proportion of *bajri*; one infers, without being certain, that the richer soils require a smaller admixture of legumes.

The question of the roles of animal manures and of leguminous plants

[1] Throughout the paper the less common leguminous plants are distinguished by **P** after their names. In quotations, **P** is necessarily an interpolation; in other cases the author's own interpolations are distinguished by square brackets.

[2] By supplying books [4], [5], and [6], and the quotation [7]. Many other references could be given.

in rotations is of considerable interest. There is evidence that one may supplement or replace the other, but as yet no experiment has been designed to test these points specifically. Since in native Indian agricultural economy, cattle and other organic manures are usually insufficient in amount, and artificials can rarely be bought, the value of the leguminous component of mixed crops emerges even more clearly than it does from a consideration of our home pastures. Voelcker [8] is definite:

> It is quite a mistake to suppose that Rotation is not understood or appreciated in India. The contrary is the case. Frequently more than one crop at a time may be seen occupying the same ground, but one is very apt to forget that this is really an instance of rotation being followed. . . . The next year the same 'mixed crops' may be grown again, and thus to the casual observer it might appear that continuous cropping was being practised. This, however, is not so, for there is a perfect rotation of cereal and legume. (Para. 304, 'Mixed crops'.)

In his survey of agricultural India in 1887, Wallace [9] devoted a special chapter to 'Rotations and mixed crops'. He wrote:

> The growth of mixed crops is a wide-spread practice which is well worth consideration and study. . . . The advantages under Indian conditions are distinctly great. . . . There is but one explanation of the existence of these practices [of mixed cropping], viz., that they have been found advantageous after long experience and much careful consideration on the part of a body of workers who, for power of observation and an intelligent interest in and knowledge of everyday occurrences, would put to shame those classes which hold a corresponding position in educated Europe.

Wallace set forth, as did Mann [4, 5], the reasons usually given for the benefits of mixed cropping, and stated that the roots of different species possess different root-habits and different functional powers. The case for studying root-habit in India has been forcibly put by Howard [10] in a chapter especially devoted to 'The Economic Significance of Root-Development'. So far as the author is aware, the only study of root-interactions of crops grown singly and mixed is that made in Austria by Kaserer [11], whose valuable paper has been much neglected. Kaserer noted that there was little or no interpenetration of roots of plants of the same species grown together, however densely, whilst an increasing degree of interpenetration was noted with increasing dissimilarity of two species grown together. A legume and a non-legume showed the maximum of interpenetration; in Kaserer's words: 'Eine Graminee mit einer Leguminose zeigte stets Verfilzung.'

Kaserer's observations have an evident relation to the uptake by one plant, of nutrients produced or made available by another. The author, with Thornton at Rothamsted, has noted the fact that the roots of lucerne and of grass, grown together in sand-pots, are separable with difficulty, whereas no difficulty has been experienced in parting the root-systems of plants of lucerne, grass, peas, and clover, grown in single culture under similar conditions.

To Wallace might perhaps be given the credit of priority already accorded by the author [2] to Leather [12], who wondered from a consideration of the Cawnpore gram **P** and wheat mixture, whether 'the

Papilionaceae are able to assist in any way the plant of another natural order *which is growing alongside them*'. Wallace wrote [9]:

I am inclined, also, to think that there may be decaying roots or matters thrown off by plants of distinct species, which matters, in the hot climate, become available within the period of growth of a given mixed crop; and, in the case of a grain crop grown along with a mixture of pulse, we may have more or less of a beneficial action, such as that of the well-known influence of clover root upon a succeeding wheat crop.

Wallace did not recall in this connexion the British pastures, with their leguminous herbage, or the practice of sowing clover in barley. Similar omissions were made by Lawes and Gilbert, Munro and Beaven, and others (Nicol [2]).

The value of having leguminous and other plants and trees in mixed culture with tea has been extensively discussed. Mann [13] has given thorough consideration to the effects, upon growth of tea, of *sau* (*Albizzia stipulata*) **P**, and several other species of trees, bushes, and crops. He wrote in 1907 [13]: 'It has been suggested that possibly the tea root gets actually in contact with the root of the *Albizzia* tree and draws nourishment from it.' In view of Kaserer's [11] and the author's observations upon *Verfilzung*, it may be hoped that more concentration will be given to the subject of the so-called 'shade' cropping in tea gardens; a study of root-habits should be particularly helpful.

The part played by leguminous 'weeds' under natural, wild, and semi-natural conditions, in maintaining and restoring the level of fertility of soils, is also striking, though it has received relatively little attention. By way of illustration of the perseverance of Nature in building up poor land, it may be remarked that upon the continuously cropped Broadbalk wheat-field at Rothamsted (in theory a pure culture) an abundant growth of wild black medick (*Medicago lupulina*) **P** frequently occurs on all of the cropped plots receiving no nitrogen or the lowest dressing of nitrogen.[1] The darkening of the otherwise bare stubbles by the green *Medicago* after the 1934 harvest was sufficiently evident to be photographable by the author. Wallace [9] commented upon the richness in legumes of the natural Indian flora, and assigned to them an important part in maintaining fertility in uncropped land.

Apparently it is not essential in Indian agriculture that a mixed crop should include a legume, since the association of *jowar* and safflower (*Carthamus tinctorius*) is recorded by Mann [5], and other examples could be given. Nevertheless, leguminous plants occur in Indian mixtures with great frequency. Mollison [6] brings out this point clearly:

Various pulses, oil-seeds and fibre crops are generally grown with *kharif jowár* [*Sorghum vulgare*, a grain; *kharif* is the name of a season]. In Gujarát there is a greater variety than elsewhere. There, subordinate to *jowár*, we find *tuver* [*Cajanus*

[1] The absence of legumes from plots receiving the higher doses of nitrogen does not imply that the nitrogenous manure was toxic to leguminous plants; it almost certainly meant that ample manuring encouraged growth of the wheat sufficiently to 'smother' the low-growing black medick. Analogous observations on clover under-sown in barley were made at Woburn by Dr. H. H. Mann, who agreed with the author that the Broadbalk phenomena helped to furnish an explanation.

indicus **P**], *guvár* [*Cyamopsis psoraloides* **P**], *math* [*Phaseolus aconitifolius* **P**], *mag* [*P. mungo* **P**], *chola* [*Vigna catjang* **P**], *adad* [*Phaseolus mungo* var. *radiatus* **P**] (all pulses), castors and *tal* [*Sesamum indicum*] (oil-seeds), and *ambádi* [*Hibiscus cannabinus*] and *rozi* cotton (fibre plants). The group of subordinate crops referred to are not often sown all together, but mixed according to the fancy or inclination of the cultivator. In Khándesh, *udid* **P** [= *adad*] and *ambádi* are ordinarily sown with *jowár*. In the black soil of Surat, *tuver* **P** is always subordinate to *jowár*, and generally also *mag* **P**. In the Deccan, on mixed black soil, *tur* **P**, *ambádi*, *udid* **P**, and sesamum, and on distinctly light soil, *math* **P**, *kulthi* **P** and sometimes niger seed [*Guizotia abyssinica*] are generally subordinate to *jowár*.

Discussing the figures recorded for the acreage of *jowar*, Mollison [6] wrote:

These figures are, to some extent, misleading, because it is the general practice to grow *jowári* and nearly all cereals with a subordinate pulse mixture.

The latter point is borne out in his detailed descriptions, later in the book, of the methods of cultivation of other grains.

The following is an excerpt from an article by Mollison [7], written when he was Inspector-General of Agriculture in India:

The common Indian system of growing mixed crops serves in many respects the purposes of rotation. It is undoubtedly a successful and profitable method, which has done more to uphold the fertility of Indian soils than any other practice. There are very good reasons why it is profitable to grow pulses, oil-seeds, and fibre plants mixed with or subordinate to cereals like *jowar*, *bajri*, or wheat. . . . Pulse crops whether grown alone or in combination with other crops, exercise another beneficial influence in that they enrich the soil with nitrogen, of which element Indian soils require a frequently renewed supply. The common growth of these pulses is a testimony to the fundamental soundness of the traditional agricultural practice of the country. No pulse crop cultivated in India exercises such a general fertilizing effect as *arhar* (*Cajanus indicus*) **P**. It is grown in every province mixed with other crops: its long tap-root enables it to withstand drought and to search in the subsoil for plant food: it spreads out and grows freely after the cereal to which it is subordinate has been harvested; and nearly all the leaves fall as the plants ripen, thus enriching the surface soil.

Custom varies in different districts. Thus, gram **P** and wheat or barley, a common mixture in the North-West Provinces, is unknown in the Bombay Presidency [6]. Mann [5], however, states that the cultivation of gram **P** in Bombay Presidency is intimately associated with that of wheat, gram having generally been considered as the natural rotation crop with wheat.

Regarding native agricultural methods in West Africa, Irvine [14] confirms the praise for mixed cropping already given by observers in India:

Mixed cropping is really a modified form of crop rotation and has several advantages. . . . Sometimes, the two or more crops growing together use different quantities of the available plant food, and their roots go to different depths in the soil. In this respect mixed cropping is more scientific than pure cropping.

An additional advantage claimed by Irvine for mixed cropping is the reduction of damage by insects.

Willis made several references in his book [15] to mixed cultivation and the similarity of its effects to rotation.

> Mixture of crops, which seems to bring in its train some of the advantages of rotation, is very common, especially in the more equatorial parts of the tropics, such as southern Ceylon, Malaya, the West Indies, &c. Not only is there . . . mixture of perennial crops, but mixture of annuals is very common in the East: pulses are sown among the grain, different kinds of grain with one another, and so on. Here again the gain is somewhat like that obtained by rotation. . . .

Of 'the wild jungle-like mixture' of trees and vegetables which forms the average native garden throughout southern Asia, Willis wrote:

> As pointed out above, it is highly probable that this arrangement gives many of the advantages which have elsewhere to be attained by rotation of crops, and the villager is thus able to grow his familiar foods, &c., on the same ground for an indefinite number of years. Mixture of crops, as well as rotation, requires very careful study in detail before any hasty attempt is made to change immemorial custom.

In the minds of many agriculturists, the customs of the Red Indians of North America are distinguished by their occasional practice of burying a piece of fish in each 'hill' of maize. This is often recalled as an example of primitive manuring. The author was aware of this practice but imagined that the maize was grown in pure culture, not having read or heard anything to the contrary. Consultation of the early part of Carrier's book [16] did not remove this impression, until on page 94 three quotations concerning mixed cropping were found. It is odd that Carrier has not thought it worth while to bring into relief, in his text, the practice of mixed cropping, since many other cultural operations are considered at length by him.

Hariot [17] wrote (*v* having been substituted for *u*):

> All the aforesaide commodities for victuall are set or sowed, sometimes in groundes a part and severally by themselves; but for the most part together in one ground mixtly. . . . The ground they never fatten with mucke, dounge or any other thing. . . .
>
> Then their setting or sowing is after this manner. . . . First for their corne. . . . By this meanes there is a yarde spare ground betwene every hole [each containing four seeds of maize]: where according to discretion here and there, they set as many Beanes and Peaze: in divers places also among the seedes of *Macocqwer*, *Melden*, and *Planta Solis*.
>
> The ground being thus set according to the rate by us experimented, an English Acre conteining fourtie pearches in length, and foure in breadth, doeth there yeeld in croppe or ofcome of corne, beanes, and peaze, at the least two hũdred London bushelles: besides the *Macocqwer*, *Melden*, and *Planta Solis*.

Hariot also wrote of the celerity with which the ground was sown; and the abundant mixed crop yielded from ground 'having once borne corne before'. Roanoke, the part of 'Virginia' described by Hariot, is now assigned to North Carolina. Carrier [16] did not quote the first paragraph here cited from Hariot.

From Pinkerton [18], after Carrier [16]:

> They (Indians) make heaps like mole hills each about $2\frac{1}{2}$ feet from the others which they sow or plant in April with maize in each heap 5 or 6 grains, in the

middle of May when the maize is the height of a finger or more they plant in each heap 3 or 4 Turkish beanes which they grow up with and against the maize.

Of Indian maize-planting in Virginia in 1606, John Smith wrote [19]:

They make a hole in the earth with a sticke, and into it they put foure graines of wheate and two of beanes.

On page 96 of his book Carrier has reproduced a picture (ascribed to Le Moyne, 1564), showing Indians planting corn and beans in the same field.

Discussion

The foregoing review is intended to be indicative rather than exhaustive. All the authors consulted agree in assigning a prominent part to mixed cropping in primitive agriculture. No author has been found who has denied its existence. Although several sources consulted (such as the works of Fortune, Huc, King, and others on China and Japan) do not mention mixed cropping unless incidentally or in relation to intensive gardening,[1] it seems probable that in many cases the omission is due to a one-sided orientation. With the Red Indians, for example, the case is clear, yet Carrier did not refer in his own text to mixed cropping as such, and omitted the first paragraph of Hariot given above. Although he claimed that the Red Indians were pioneers of intertillage for keeping down weeds, he did not mention intercropping. On the subject of rotation, Carrier wrote that the Red Indians practised a rotation of fields rather than of crops. His example shows how easy it is to miss a point. Probably the absence of specific remarks upon mixed cropping in the recorded observations of many authors is not to be taken as evidence of absence of the cultivation of mixtures.

Clover and barley, and clover in grassland, have already been referred to, as examples of mixed cropping overlooked in his native land by so astute an observer as Wallace.[2]

Administrators in India have recognized the fiscal importance of mixed cropping, by drawing up rules for the estimation of the areas to be ascribed to each component of mixtures. It is therefore remarkable that, in spite of repeated recommendations, the agricultural problems underlying the practices of mixed cropping have been so little studied. In

[1] A French observer, Hedde [20], under the heading 'Fruchtwechsel' wrote as follows: 'Die Chinesen verstehen sich dergestalt auf die Unterhaltung der Erde durch die Kombination der veränderten Kulturen, dass man sich zu der Aeusserung veranlasst fühlte: "Der Ackerbau wäre bei ihnen Gartenbau." Sie glauben nicht daran, dass die durch die Erbauung der verschiedenen Pflanzen bewirkte Arbeit die Erde jemals erschöpfe; im Gegentheil nehmen sie an, dass, wenn eine Pflanze einen besondern, ihr nothwendigen Stoff absorbire, sie, als eine Ausgleichung, ein neues Element oder einen natürlichen, einer andern Kultur günstigen Düngstoff zurücklasse.'

Fortune [21] wrote of mixed crops in Chinese tea plantations: 'Another reason for the practice may be found in the fondness of the Chinese for mixing crops—a practice in operation all over the country.'

[2] Wallace in his chapter on 'Rotations and Mixed Crops' [8] wrote: 'The system is more or less known in this country [Britain], though not extensively followed!'

para. 60, Voelcker [8] remarked, apropos of the then recent discovery of nitrogen-fixation by legumes and their nodule bacteria:

India, to my mind, presents special advantages for the elucidation of the problem, one which, when solved, will unfold much that is still unexplained in the advantage of rotation of crops.

One of the most remarkable effects of the leguminous crop, whether in mixture or in rotation, is its apparent ability to supplement animal manures. In peninsular Indian practice (the best-studied case) it would seem that legumes grown in mixture can to a large extent fill the place of animal manures. It appears unlikely that this ability is due solely to the nutrient nitrogen compounds supplied by the legumes, and it is probable that leguminous plants everywhere make a definitely biological contribution to the fertility of soil.

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INST. AGR. RES.

THE DRY-MATTER CONTENT OF CERTAIN GRASS AND CLOVER SPECIES

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INVESTIGATIONS conducted at the Welsh Plant Breeding Station on the dry-matter content of herbage plants have shown that variation exists in this respect among species, but that certain factors have an influence upon dry matter apart from species and strain. Thus Stapledon [1], working on grasses during the seasons 1921–3, and Williams [2] on red clovers, found that whilst differences in the percentage of dry matter occurred among the individual species and strains, the precise values were largely influenced by total yield, by the number of cuts taken, and by the meteorological conditions obtaining from the commencement of the growing season.

Sheehy [3, 4] has conducted experiments which indicate that the dry-matter content of pastures is of considerable importance in determining their stock-carrying and fattening capacities. He has shown that differences in the percentage dry matter of the grass, clover, and miscellaneous herb groups are so marked that the value of a pasture is to a large extent determined by the relative proportions of these three groups.

The experiment reported upon in the present paper comprises an investigation supplementary to one on dry-matter content conducted by the writer [5] in 1933.

The Experiment

In the experiment species and strains of grass and strains of red clover were sown in 20 ft. drills, on which a series of pasture-, hay-, and aftermath-cuts were made for percentage dry-matter determinations. For this purpose air-tight 3-litre bottles of known weight were used on the field. The net weight of fresh herbage was obtained by difference, and later the herbage was dried in an oven.

Two pasture-cuts were taken in the autumn of the seeding year (1933) and five more during the following year. The time of cutting was determined by the stage of growth. An early hay-cut was taken from a separate portion of each drill when the herbage was in the heading stage.

Results

The data for the three modes of cutting are given in Table 1. Considering the pasture-cuts first, there are distinct differences in the percentage of dry matter among the species.

Fine-leaved fescue, timothy, and meadow foxtail have given the highest percentages, Italian rye-grass the lowest. It will be observed that red clover is among the lowest, but that it is equal to perennial rye-grass. The data on the grasses are in agreement with the previous investigation by Stapledon [1].

TABLE 1. *Percentage of Dry Matter in Grass Species and Red Clover cut as Pasture, Hay, and Aftermath*

Species	*Number of strains averaged*	*Average of 7 pasture cuts*	*Early hay*	*Aftermath*
Perennial rye-grass	19	23·2	23·9	34·2
Italian rye-grass	3	21·3	23·3	32·0
Cocksfoot	27	23·9	25·5	30·3
Timothy	14	28·4	29·2	29·6
Meadow fescue	7	26·9	25·7	32·9
Tall fescue	3	24·3	24·0	33·3
Crested dogstail	3	25·3	28·0	32·0
Meadow foxtail	5	27·6	28·2	33·0
Fine-leaved fescue	8	28·9	27·7	30·2
Bent (*Agrostis* spp.)	2	26·5	23·0	32·0
Sweet vernal	2	26·0	30·5	28·5
Bromus arvensis	1	27·0	28·0	37·0
Red clover	6	23·2	23·5	24·9

Considering next the data for hay and aftermath, the position of the species in respect of one another is the same as in the pasture-cuts for the majority of the species, exceptions being that cocksfoot, crested dogstail, and sweet vernal have risen in relation to the others, whilst fine-leaved fescue and bent have dropped. The aftermath figures show that perennial and Italian rye-grasses and tall fescue have given higher percentages in relation to the other species than they did as pasture or as hay, but that the reverse is the case with timothy and sweet vernal. Red clover again gave one of the lowest percentages of dry matter.

The most marked feature of the table is that the figures for the hay-cut are on the same level as those for pasture, and that the figures for the aftermath are the highest of all. This aspect of the results will be dealt with later in the discussion.

In Table 2 particulars are given of the percentage dry-matter of the species for the seven pasture-cuts.

The first cut on September 22, 1933, represents growth from the time of sowing on May 5, and the cut on May 7, 1934, represents the accumulated growth throughout the spring. It will be observed that every species shows the same trend, namely, a drop from the relatively high percentage figures of the autumn cuts to those for May 7, and to the still lower figures for May 29: then a sharp rise to those for July 9, succeeded by a fall to August 14; and then, in the majority of cases, a rise to the cut on October 16. It is significant that, without exception, the species have given this seasonal fluctuation in their percentage dry matter; and that the herbage of most of the species, on November 18, consisting entirely of autumn growth, contained more dry matter than the herbage on July 9.

Discussion

A comparison of the data for pasture with those obtained by the writer [5] from grazed plots illustrates the effect of cutting *versus* grazing

TABLE 2. *Percentage of Dry Matter in the Species at each Pasture-cut*

Species	Date of cut						
	Sept. 22	*Nov. 18*	*May 7*	*May 29*	*July 9*	*Aug. 14*	*Oct. 16*
Perennial rye-grass	27·0	27·2	21·7	19·4	29·7	18·4	24·7
Italian rye-grass	23·0	18·5	17·7	18·3	28·3	20·0	21·0
Cocksfoot	29·2	28·2	20·8	17·2	26·5	20·1	27·2
Timothy	33·9	33·9	29·0	19·4	32·3	21·7	29·0
Meadow fescue	35·0	29·2	25·1	16·9	28·0	25·4	26·3
Tall fescue	24·6	30·0	22·6	20·3	24·3	22·3	25·0
Crested dogstail	26·0	34·0	23·0	16·3	33·0	25·6	22·0
Meadow foxtail	33·8	32·0	24·6	16·6	31·2	26·0	32·7
Fine-leaved fescue	*	*	33·7	21·3	32·2	26·9	29·4
Bent (*Agrostis* spp.)	*	*	28·0	21·5	27·5	25·0	30·0
Sweet vernal	30·0	38·0	24·5	17·0	35·0	25·0	30·0
Bromus arvensis	27·0	43·0	13·0	11·0	34·0	33·0	27·0
Red clover	26·3	27·5	19·7	16·5	24·8	23·6	*

* Not sufficient material for analysis.

conditions upon the percentage dry-matter content of herbage. In the earlier work samples were taken at several dates in 1933 from plots of pure species which were grazed at three-weekly intervals. The percentage dry-matter of these samples was as follows:

	May 19	*June 15*	*July 11*
Timothy	15·4	23·8	16·6
Bent (*Agrostis* spp.)	23·6	37·8	24·7
Yorkshire fog	14·8	25·1	18·0
Cocksfoot	18·0	25·8	20·1
Meadow fescue	17·0	26·3	21·4
Tall fescue	19·4	29·4	20·7
Fine-leaved red fescue	21·6	28·8	24·4
Perennial rye-grass	17·5	27·3	19·5
Italian rye-grass	14·0	25·6	16·4
Montgomery red clover	17·0	25·6	18·3
Wild white clover	15·2	20·3	16·0

It will be observed that in these data timothy gave figures which were among the lowest for the grasses, whereas under the cutting system it was one of the highest. Under grazing conditions, on the other hand, bent gave significantly higher figures for dry matter than any of the other grasses, but it occupied only an intermediate position in the range of species under the condition of pasture-cuts.

The reason for these differences is that in the case of timothy it was observed that the sheep grazed this species to such a close degree that, although not sampled for dry matter until three weeks' rest had elapsed, the herbage recommenced growth from the very base and was wholly of an immature and succulent nature and consequently of a low dry-matter content.

With bent the opposite was the case, for being of relatively low palatability the herbage sampled always contained a certain amount of mature growth which would have been left ungrazed at the previous date, notwithstanding the fact that any ungrazed herbage was scythed off immediately after each grazing. It was noticed that the scythe never cut a poorly grazed plot as closely as the sheep grazed a very palatable plot.

As a matter of fact, these data from grazed plots give a more accurate picture of the dry-matter content of pastures than the data from the series of pasture-cuts. In farm practice, moreover, where pastures are often under a system of continuous grazing, the differences in the percentage dry-matter content of the most palatable grasses and the least palatable grasses would be still more marked than in the foregoing examination, on account of the animals grazing the former rigorously and to a great extent neglecting the latter.

It will be noted that the dry-matter content of the red clover in the grazed plots gave figures as high as some of the grasses, but that wild white clover gave figures which were lower than those for red clover at each date of sampling.

An examination of the strains of grasses within a species showed no consistent differences in favour of any particular source of origin. The results obtained for the strains of red clover are in keeping with the evidence reported by Williams [2].

The seasonal fluctuation in percentage dry matter which the species showed in the pasture-cuts coincides with the data of Stapledon [1] in his earlier investigation, where he found that the depressions and peaks occur around the dates mentioned, and that the periods of low-percentage dry matter corresponded with greatest total yield. Williams [2] found this negative correlation between percentage dry matter and total yield to be very marked in red clover.

When commenting on the particulars given in Table 1, attention was drawn to the relationship of the figures for pasture, hay, and aftermath. The fact that the percentage dry matter is low in herbage during the end of May and early June accounts for the hay-crop cut in the heading stage on June 12 giving such low figures compared with those for pasture and aftermath. In this connexion Sutton and Voelcker [6] found that hay cut at the heading stage from a permanent sward gave 24·8 per cent. of dry matter, a figure corresponding to that for the species in the hay-cut of the present trial, whereas hay cut at or after the flowering stage gave 32·5 per cent. of dry matter. The high figures for the dry-matter content of the species in the aftermath which was cut on August 30 are accounted for by the herbage of this cut having been an accumulation of the summer growth, the aftermath having been taken after an early hay-cut. Stapledon [1] has shown that length of growing-period affects dry-matter content; moreover, Fagan and Watkin [7] working on the oat plant found that the percentage of dry matter increased with maturity.

Sheehy [3] found as much as 25 per cent. more dry matter in the herbage of one pasture than in that of another, but as the percentage of dry matter in the grass portion of the poorer pasture was similar to that

for the total herbage of the better pasture, which was predominantly grass, he attributes the difference to the relatively high proportion of miscellaneous herbs present in the poorer pasture. It is, however, interesting to observe that in view of the data on grass species referred to and reported upon in the present paper, the percentage of dry matter will differ from pasture to pasture both in accordance with the grass species that dominate the sward and with the intensity of the grazing. Thus a poor-class pasture containing bent (*Agrostis* spp.) as its chief grass will contain a higher percentage of dry matter in the grass portion of its herbage than a pasture containing perennial rye-grass as its dominant grass.

Crampton [8] points out that because grasses have a greater dry-matter content than clovers it does not follow that they will yield more net energy to animals, for in regard to feed the fibre-content has to be considered. He describes the undesirable effects of fibre in the feed and cites figures to show the lower percentage of fibre in white clover compared with that in certain grasses, thus concluding that difference in fibre-content may tend to balance the lower dry-matter content of clovers and higher dry matter of grasses. In view of the data here under discussion it would seem that this comparison would apply chiefly to wild white clover in permanent pastures and only to a lesser degree to red clover in temporary swards.

Summary

An investigation has been made into the percentage of dry matter of grass species and red clover when cut as pasture, hay, and aftermath.

Differences among the species were found to occur under each system of cutting.

The pasture-cuts showed marked seasonal variation, the lowest percentage dry matter occurring during late May and early June, when maximum growth is being made. The pasture-cuts in July, October, and November, gave the highest figures of the series for dry matter.

A comparison of the data with those of previous work showed that the dry-matter content of a species when grown under grazing conditions is affected by its palatability.

The species when cut for hay in the heading stage gave figures for percentage dry matter similar to the average of the pasture-cuts. The subsequent aftermath, consisting of mature herbage, gave higher dry-matter content than the hay and pasture.

The influence of percentage dry matter of herbage on the value of pastures is discussed.

Acknowledgement

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OBSERVATIONS ON COFFEE IN KENYA

INTRODUCTORY *by* A. D. TRENCH, *Senior Coffee Officer, and* V. A. BECKLEY, *Senior Agricultural Chemist, Kenya Department of Agriculture, and*

Pt. I, CHLOROSIS AND DIE-BACK IN COFFEE, *by* V. A. BECKLEY

With Plates 13, 14

Introductory

COFFEE, *Coffea arabica*, has been grown in the Highlands of Kenya for a good many years, but it is only during the past seven or eight years that it has been possible for any concerted scientific observations to be made on the real cultural side of coffee-growing. The information accumulated during these years has shown us that coffee is a crop that is capable of adapting itself to widely divergent conditions and behaving differently under each set.

Under a certain concatenation of conditions, active root-growth occurs during the rainy seasons, under another set the roots are most active when the content of soil moisture is not too high, after the rains. Sometimes the cutting of a main lateral root involves the nearly complete loss of the functions of that root; a mass of short hair-roots develops only at the cut end. Elsewhere the effect of cutting a root is ephemeral. Again, in some parts coffee will bear a good crop year after year; in others a good crop is accompanied by very severe die-back and there is no crop the next year.

Such variable behaviour complicates all advisory work. Cultivation methods, cultural practices, and manurial treatments have all to be adjusted in order to meet the reactions of the plant to each set of conditions. It is impossible to generalize beyond simple basal concepts.

These same wide variations in habit observed, have encouraged us to take advantage of the foundation ideal of the *Empire Journal of Experimental Agriculture* and publish the various observations of the officers of the Department of Agriculture, Kenya, concerned in coffee investigational work, in the hope that these may be of help to other workers on coffee, and in the hope that they too will publish their observations to be of assistance to us. It is proposed to publish at intervals a series of papers on all the aspects of the work now in progress on coffee cultural practices.

I. CHLOROSIS AND DIE-BACK IN COFFEE

Chlorosis and die-back are troubles encountered in coffee-cultivation everywhere. In East Africa whole plantations may become chlorotic, showing up as yellow patches in the general landscape, and very often accompanied by severe die-back of branches. Usually it is only trees carrying a crop that suffer chlorosis, but sometimes chlorosis will persist after the crop has been picked, and certain forms may occur whether a crop is being carried or not. The causes of the condition have been a matter of speculation or have been overlooked.

In 1929–30, after a season of long continued heavy rain, chlorosis was almost universal in Kenya. The condition was shown by the writer [1] to be due to a lack of available nitrogen while the crop was developing. Sanders and Wakefield [2, 3, 4] consider that the chlorosis and die-back occurring in the Northern Province, Tanganyika Territory, is due to an inadequate supply of nitrates at the period of maximum demand, and ascribe chlorosis during the rains to waterlogging with possible denitrification. Nutman [5] on the contrary, attributes chlorosis and die-back to a deficiency in the carbohydrate-supply during the period of heavy demand.

Investigations during the past three years have led the writer to the conclusion that in East Africa there are at least two main types of chlorosis and die-back recognizably due to physiological disturbances. One is directly due to an inadequate supply of available nitrogen at the period of greatest demand, and can be alleviated by the application of a readily available nitrogenous fertilizer, provided the soil-moisture conditions are suitable. The other main type is definitely ascribable to a deficiency in the carbohydrate-supply while the crop is developing most rapidly and can only be alleviated by stripping the crop; it is, in fact, a case of sheer overbearing. In each form there are certain symptoms which are readily recognized, and so it is possible to adjust the treatment to the needs of the case. The matter is somewhat complicated by the fact that both forms occur simultaneously.

Two other types of chlorosis, certainly due to physiological disturbances, have been recognized. Although the ultimate causes are not known, the symptoms will be described. It is recognized that both chlorosis and die-back may be caused by insect damage or the effects of disease organisms, but this aspect of the subject is beyond the purview of this paper.

Chlorosis due primarily to nitrogen-deficiency.—This form of chlorosis is the commonest type found in coffee on the eastern side of the Rift Valley and thus has been closely studied for some years. The symptoms of nitrogen-deficiency in the field are easily recognized and have been described [6]. Under extreme lack of nitrogen, such as can be arranged in pot-experiments, trees, as is to be expected, are chlorotic, but under field conditions chlorosis appears only when a crop is carried. Any operation or condition liable to lead to a shortage of available nitrogen, such as long-continued rain or drought, poor or denuded soil improperly managed or grassed, or the ploughing under of a strawy green manure among others, will cause bearing trees to turn yellow and perhaps to suffer die-back.

The first stage in the chlorosis is a paling of the normal dark green colour of the leaves. Any leaves produced at this stage are undersized. The main veins turn yellow and mature leaves are apt to be shed; the yellow colour spreads from the veins until almost the whole blade of the leaf is involved. The tone of the colour is rather a lemon yellow. Nearly mature leaves are shed and the yellow apical leaves together with the growing point die. Usually the apical leaves drop off as they die, and it is the writer's belief that, in die-back due purely to nitrogen-deficiency,

the shedding of the apical leaves is typical, and that where they are retained there is another contributory factor. The death of the growing-point is followed by a progressive dying-back of the branch, which may involve the whole, spoiling the tree. Innumerable cases have been observed where the middle primaries have thus been lost, giving a tree consisting of two tufts, a large bottom tuft and a small upper one, with a length of bare stem between.

The crop suffers severely. Although a large crop of cherry may be ripened, the output of clean coffee will be very low. In one case only 2 per cent. of good coffee in place of the usual 22–5 per cent. was obtained from the cherry picked; most of the cherry was either empty or contained fragmentary beans. Cross-sectioning cherries from trees in a state of die-back forms one of the most valuable means of diagnosis, the sections showing various stages in the formation of empty beans (Fig. 1, Plate 13). Chlorosis usually starts when the bean is passing from the 'water' to the 'milk' stage; thus any changes in the macro-structure of the bean are easily seen. In many cases a small clear green patch will be seen at the basal end of the white endosperm, indicating a mobilization of food stored in the seed; such a patch is visible in the lower bean of Fig. 1*b*. The mobilization and transport of deposited food either to the contiguous bean or to other cherries proceed, in deficiency of nitrogen, until either only a thin cellulosic membrane or a fragment of the bean is left. In the cross-section shown in Fig. 1*e*, one bean has been broken down almost completely; in the longitudinal section, Fig. 1*f*, only a membrane is left of one bean and a small fragment of the other. Since die-back almost always accompanies severe chlorosis, breaking-down of the beans always starts at the distal end of the branch, and, if die-back is not too severe, quite good coffee may be picked from the basal ends of bearing branches.

There is a liability for true breaking-down of the beans to be confused with the collapse of beans due to drought conditions, especially when collapse occurs during the early stages of development. In collapsed beans the whole endosperm shrinks away from the parchment-like endocarp; breaking-down starts from one end of the folded sperm.

The application of a readily available nitrogenous manure not only arrests the breaking-down of the crop but also, if breaking-down has not proceeded too far, food is redeposited. In one case where a whole plantation had become chlorotic an application of a nitrogenous fertilizer was advised. At the time it was found by cutting across cherries, picked at random from a number of trees, that more than one-half of the beans were breaking down. Two months later, although chlorosis was still evident, it was difficult to find any beans breaking down; die-back, too, had been arrested. Next year the trees were healthy and vigorous and carried a good crop. In another case, that of a single tree in the grounds of the laboratory, growing on soil which had suffered erosion, the tree was permitted to get into an advanced condition of die-back, so that practically every cherry examined showed beans breaking down. Since the soil was dry, a 500 gm. lot of ammonium nitrate was applied in solution and well watered in. A similar quantity of water was applied to another chlorotic tree. A month later both trees were still chlorotic, but in the tree that

had been treated with nitrogen die-back was arrested and all beans were full; in the other die-back was proceeding actively and there was well over 60 per cent. of empty beans. The ripened crop from the treated tree gave a good out-turn of clean coffee; the crop on the untreated tree failed to ripen; it dried on the tree. The treated tree soon produced new growth and was fit to carry a crop next season. The untreated tree suffered from very severe die-back, lost many of its primaries, and was incapable of carrying a crop next season; in fact, it was necessary to stump the tree.

The roots of many trees suffering from nitrogen-deficiency, chlorosis, and die-back have been examined. In no case has there been any recognizable death of the roots. Fig. 2 (Plate 13) is a diagram of the root-system of a coffee-tree which the year previously had suffered from severe chlorosis and die-back. Sections cut of main lateral roots of trees in a state of die-back have always been found to contain large quantities of starch granules. The simpler test of putting iodine on a cut surface has always been positive for starch.

Chlorosis due to inadequate carbohydrate-supply.—The early stages of this form of chlorosis are very similar to those described above. The colour, however, is more of a buff yellow than lemon yellow, but it is very difficult to differentiate between the two colours, other chlorosis-effects being liable to complicate matters. A marked difference occurs when the apical leaves die. Death of the twig begins not from the terminal bud but from the point where green immature wood starts; perhaps three internodes will collapse and die. The dead apical leaves may be retained for some weeks before they finally drop. The branch then dies back in exactly the same way as before. Die-back may sometimes involve the whole tree.

The crop in this form of chlorosis and die-back does not suffer. The cherry is always full; even the cherries on the apical part of a shoot, which has died back early in the development of the bean, will contain some residue of a bean and not merely a shrunken residue. The crop that ripens—the full red colour does not develop—is always full and a normal output of clean coffee is obtained.

Die-back and chlorosis of this type is always accompanied by severe die-back of the roots. Laterals may die back to the main root-stock, leaving only a scar. Figs. 3 and 4 (Plate 14) illustrate the root-system and root-stock of a tree which had suffered severely from this form of chlorosis and die-back. The residue left after death is peculiar and consists of white, easily-powdered material, reminiscent of the texture of wood attacked by dry rot. One only rarely finds this residue on account of termite action, but in every case where the writer has found remains of dead roots on a tree that has suffered from carbohydrate die-back, they have been of this dead-white, easily-powdered type. Main roots which have died from other causes are usually brown and very hard.

Many trees suffering from this form of die-back have been examined and in no case has a positive test for starch been obtained. Roots, wood, and even young leafy shoots have all given negative results. The conclusion to which one is forced is that this type of chlorosis and die-back is

simply overbearing beyond the capacity of the tree, and that the tree, in order to carry the crop, mobilizes all its carbohydrate-reserves in the attempt. It appears from the die-back of the roots and the residues found, that there must be very complete mobilization of the carbohydrates, even structural materials being used so far as possible.

The application of nitrogenous fertilizers to trees dying back is of no use at all. An early application of a nitrogenous fertilizer when the crop sets or the first signs of chlorosis appear, by increasing leaf-growth, may either prevent this form of chlorosis completely or make the attack very mild.

In the year 1934, owing to long-continued drought conditions, during which photosynthesis was depressed, the carbohydrate-reserves of the trees were depleted and this type of chlorosis was very widespread. Normally, however, in Kenya it has been dominant only in those districts where the natural vegetation is the orchard bush-tall grass complex. Whether the soil and climatic conditions which have given rise to this vegetation climax are conducive to poor carbohydrate-synthesis, it is too early to say, but the occurrence is at least suggestive. Even in these areas it is noticeable that in plantations where good farming practices are employed chlorosis is absent or very faint.

This form of chlorosis and die-back is considered to be the more serious. Although a fair crop is obtained from trees in a state of die-back, the loss of most of the roots prevents the trees from being anything more than passengers for at least two years. The type of cropping Sanders and Wakefield [3] call 'biennial' and 'triennial' bearing develops, a fair crop is followed by one or two light crops. The yields in one plantation where this type of die-back is common are as follows (cwt. per acre): first year 6·4, second year 2·9, third year 6·7, fourth year 1·9; an average over the last three-year period of just under 4 cwt. per acre. Compare with this the average 6·8 cwt. per acre from a neighbouring plantation where during the last three years chlorosis and die-back have been reduced to a minimum by good farming practices and rational manuring. The plantation quoted is very much above normal for the area; there are many plantations where the effect has been very much worse. On one, the year after their first crop the trees were all chlorotic, had put out no new growth, and possessed hardly any lateral roots; root-scars showed that the trees had possessed a fair root-system before the crop was carried. On another, so severe was the effect that the owner uprooted the whole block as being unlikely to be economic.

The loss of crop on a tree suffering from chlorosis and die-back due to nitrogen-deficiency is immediately serious, but the tree very quickly recovers, especially if it is properly manured, and is soon in a fit state to carry a crop.

Other forms of chlorosis due to physiological causes.—Often the terminal leaves of coffee are found to be an even bright yellow, and, in extreme cases, malformed and twisted. This condition has been termed climatic chlorosis [1], and was thought to be due purely to climatic extremes, such as rapid temperature changes, or to sudden major weather changes. But when it was found that the young leaves of trees liable to this form of chlorosis were scorched by kerosene oils that had no effect upon

normal foliage, it was realized that there was some reason for this tenderness to climatic variation.

Among various contributory causes which have been recognized as conducive to the condition are all those which throw a strain upon the tree. Trees which are recovering from carrying an excessive crop are very likely to produce young leaves that are very sensitive to weather conditions. It is very rare to see anything but misshapen, torn, and twisted leaves on the exposed top of such a tree. The leaves produced after defoliation by caterpillars are very tender and liable to become chlorotic and malformed. Strain is not the only factor. The upper leaves of a single-stem tree, pruned into a very flat-topped form, are all liable to develop this form of chlorosis. At present it is not possible to adduce any hypothesis accounting for the production of tender leaves. At the best it can only be recognized as a condition indicating that something is wrong.

Another type of chlorosis, which is frequently encountered, especially common in trees growing on old stock *boma* (pen) or hut sites, has also defeated attempts to elucidate its ultimate cause. The veins here remain dark green against the yellow background of the leaf-blade, similar to the early stages of sulphur-deficiency chlorosis in tea, described by Storey and Leach [7].

The leaves showing this form of chlorosis are larger than usual and very soft. They contain 23 per cent. of dry matter as compared with the 35 per cent. of normal leaves. The iron-content too is especially low. It thus appeared that here one was concerned with some deficiency-disease. The soil on these old occupied sites is always less acid than the normal, the surface-soil often having a pH value above 7, as compared with the more normal, 5·5–6. It is also very rich in available phosphates, as shown by the Illinois Field Test. Heavy applications of unbalanced fertilizers and salts of many of the trace elements with and without sulphur have been applied to trees showing this form of chlorosis, without any effect upon the disease.

It has also been observed that often the young shoots on trees which have been stumped develop leafage showing this form of chlorosis. It is highly unlikely that under such conditions a mineral deficiency should be the cause of the chlorosis; the ultimate cause must be sought elsewhere. It is, however, suggestive that it does predominate on land which has been occupied by natives as stock *bomas* or as hut sites.

Summary

1. Four forms of chlorosis in coffee are described which are attributed to physiological derangements.

2. One form is ascribed to an inadequate supply of nitrogen at the period of maximum demand. It is usually accompanied by die-back and involves severe loss of crop. In this form there is no death of roots. Application of nitrogenous manures arrests loss of crop and die-back.

3. Another form, very similar in appearance, is attributed to a deficient carbohydrate-supply. It is accompanied by severe die-back both of branches and roots, but usually a fair crop is produced. Nitrogenous

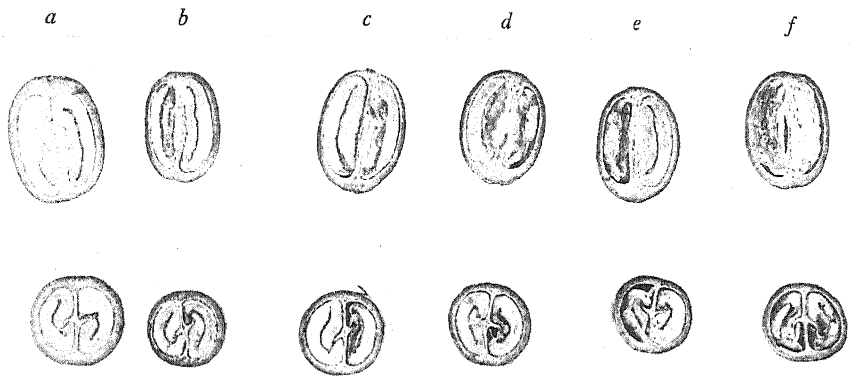

FIG. 1. Sections across green coffee cherry, showing successive stages in breaking down of bean

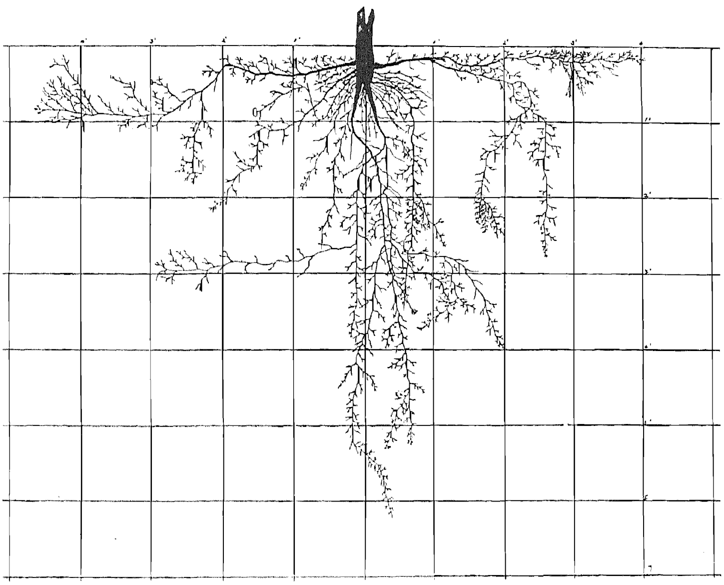

FIG. 2. Diagram of root-system of a coffee tree which had suffered severe nitrogen die-back. (1 ft. squares.)

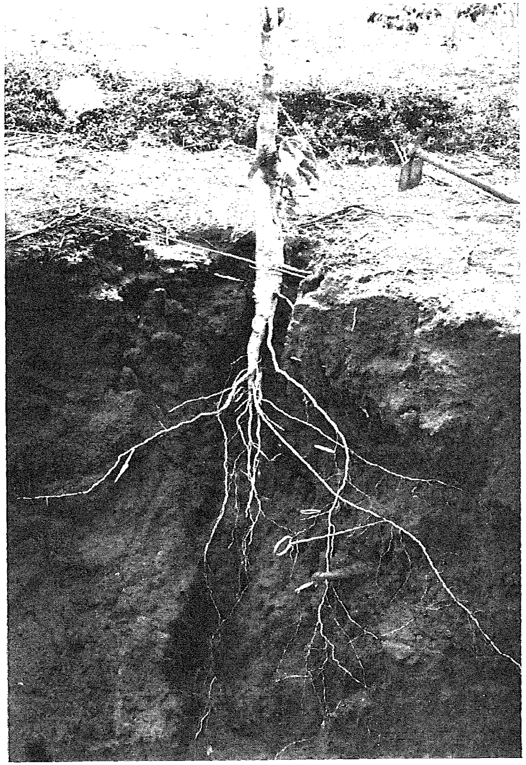

FIG. 3. Root-system of a coffee tree which has suffered severe carbohydrate die-back

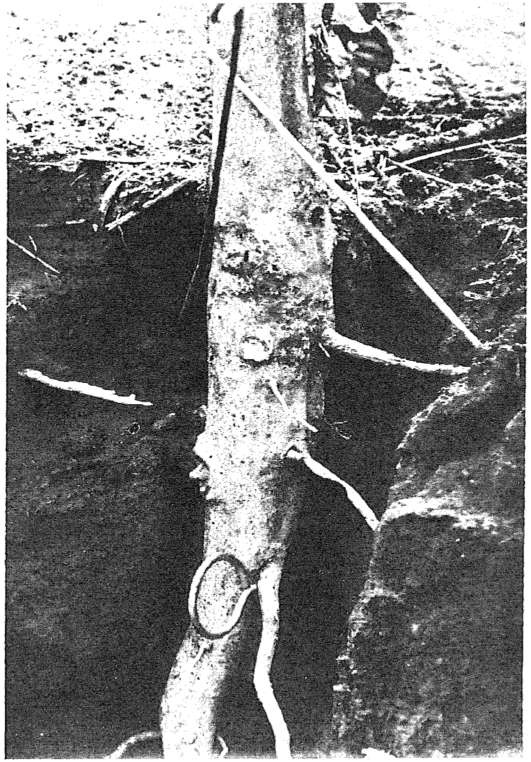

FIG. 4. Enlarged view of top of root-system of tree in Fig. 3, showing root-scars, dead roots, and developing adventitious root

manuring, unless applied very early, has no effect upon this form of die-back.

4. Two other forms have been recognized but it is not yet possible to attribute them to any definite causes.

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NOTE. Since the above was written the writer has been able to obtain Nutman's paper, 'The Root-System of *Coffea arabica*, Part II: The Effect of some Soil Conditions in modifying the "Normal" Root-System' (*Empire J. Expt. Agric.*, 1933, **1**, 285), in which he discusses the effect of die-back on the root-system. The effect of die-back of roots converting a normally deep-rooted tree into a surface-feeder has not been observed in Kenya. In every case where die-back has been severe all the roots have been involved and, as can be seen from Fig. 4, surface laterals are often completely aborted. With this exception carbohydrate die-back follows the same course in Kenya as described by Nutman.

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OBSERVATIONS ON COFFEE IN KENYA

Pt. II. VEGETATIVE PROPAGATION OF COFFEE

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With Plates 15, 16

ONE of the first things noticed in any coffee plantation in Kenya is the extremely variable population. This is due to the heterogeneous nature of seedling material; even that from a 'selfed' tree shows marked variations. There are two methods by which this variation could be overcome, by breeding and by vegetative propagation. The breeding of pure lines of coffee seed is very slow and entails many years' work covering several generations; it is therefore unsatisfactory. In consequence, some three years ago, our attention was drawn to the second method. At that time much success was being obtained with the reproduction by asexual means of other tropical crops, and it was considered that it might also be applied to *C. arabica*. It is here proposed to deal with the work which has been conducted to date.

Many possible methods of vegetative propagation have been under experiment, the results of which are dealt with under their separate headings. It should be noted that, owing to the marked polarity of coffee, all material used for cuttings or as scion wood for grafting is taken from vertical growth. Lateral wood produces only low-growing, flattened trees.

Cuttings.—It is of the greatest interest and importance to note how very closely results obtained here with coffee correspond to those obtained with cacao in Trinidad [1]. With the exception of slight variations in technique, the raising of clonal material of these two crops appears to be closely related and thus any further work conducted in Trinidad should be followed closely by those working with coffee.

Whilst the grafting of coffee has been practised in some countries, notably Java [2, 3] for many years, it is remarkable that so little work has been conducted on the propagation of coffee by cuttings. This may be due to the belief that cuttings do not produce good root-systems, or that they do not have the traditional tap-root of the seedling. That the seedling seldom produces a true tap-root but relies on a number of deep-rooting verticals is now proved, so no importance can be attached to this theory. The former suggestion is a possibility which cannot be overlooked and merits further investigation. The results of the experiments so far, nevertheless, indicate that the root-system of a 'cutting' compares very favourably with that of a seedling tree (Figs. 1 and 2, Plate 15) and that trees 2–3 years old raised from cuttings, are comparable with seedling trees of the same age. (Figs. 3 and 4, Plate 16.)

(*a*) *Hardwood.*—At the Scott Agricultural Laboratories, Nairobi, where most of the early work has been carried out, many hundreds of different types of hardwood cuttings have been planted out in open nurseries without success. In another district in Kenya with very different

climatic conditions—heavier rainfall being possibly the chief factor—a coffee planter has been highly successful with this type of cutting, the material used being prunings from trees grown on the Multiple-Stem system. Each cutting was approximately 2 ft. long and about 1–1½ in. in diameter. How these cuttings will behave when they become mature trees must await further investigation, but it is interesting to note that they are already producing a prolific root-system.

(*b*) *Softwood.*—The propagation of this type of cutting entails the use of a closed frame or propagator. Several different propagators have been tested. That which is most suitable to local conditions consists of frames artificially heated by ordinary 'hurricane' lamps in chambers beneath and with a canopy overhead. Sand, thoroughly washed and steam-sterilized, is used as the rooting medium.

The type of cutting is of the utmost importance. That which has given the greatest success, although termed softwood, really consists of a tip, having semi-hardwood at the base and allowed to retain its young tip leaves. The cutting used is 6–9 in. long and not more than ¼ in. in diameter. Very suitable material will often be found growing as a bunch of suckers on a stumped tree, generally in the centre under dense shade. Attempts are now being made to induce this type of growth on a larger scale by various methods—shading, &c. Since the tip leaves must be retained, a high humidity must be maintained in the propagator and thus the frames are opened up for a few minutes only each morning. The rooting-medium, which is kept at a temperature between 68° and 72° F., requires watering about twice a week; on the other mornings the leaves of the cuttings are subjected to a fine spray of water in order to keep them fresh. Rooting may be expected in 3 to 4 months. Attempts have been made to stimulate the initiation of root-growth by treating the cuttings with certain gases [4 and 5] prior to placing them in the propagators, but so far no success has been recorded.

(*c*) *Root and leaf cuttings.*—All attempts to propagate these types of cuttings have failed.

(*d*) *A modified form of layering.*—Both correct layering and marcotting gave success during the first experiments conducted, but owing to the tedious nature of the work, and the slow rate at which it would be possible to raise large clonal populations, other methods were sought. Early work proved that if suckers, growing from an old stumped tree, were ring-barked near the parent stump and then etiolated, they would root with comparative ease, provided suitable weather conditions prevailed. This indicated that if some method could be found whereby the parent material could be made to produce a larger area for the production of sucker-growth, little difficulty would be experienced in raising large clonal populations. Thus a technique has been evolved and whilst, owing to drought conditions, only early observations can be recorded, it is satisfactory to note that these are most hopeful. The following is the method adopted. A rooted cutting from a selected tree is planted out in a nursery at an angle of approximately 25 degrees from the horizontal. By keeping it pegged down, it will continue to grow in this plane. As this plant grows, suckers come away from the axillary buds. When

about 12 in. high they are ring-barked at the base and soil banked round them. When rooted, the soil is removed and the sucker cut away from the parent plant, which again will produce further cycles of suckers for similar treatment. In the first cycle only a few of the rooted suckers should be removed, the remainder being pegged over at right angles to the original plant to provide a larger area for the production of rooting-material in the second and subsequent cycles. Experimentation has shown that earthing up must not be carried out until the suckers are ready for rooting, and even then it is necessary to ring-bark each sucker.

Budding.—When the study of the vegetative propagation of coffee was started, considerable attention was given to the possibilities of budding, but as it has been found that the technique presents several difficulties, the method has been abandoned in favour of grafting. It is of interest to note that in referring to budding, Marshall [6] says: 'The union of stock and scion is much weaker than when grafting is used. In heavy wind the entire growth is liable to break back to where the original bud was inserted.'

Grafting.—Grafting has been widely used in Java where, due to the self-sterility of *robusta* coffee, decreased yields have always been recorded from monoclonal plantations [7]. This difficulty is now being overcome by the interplanting of different clones or by the introduction of a number of seedling trees. Fortunately, *arabica* coffee, being a self-fertilized plant, will not present the same problem. Considerable success has already been achieved with different methods of grafting in Kenya.

Grafting by inarching.—Methods of inarching young seedlings in the nursery and of inarching one-year-old plants upon old stumped trees in the field was first attempted with considerable success by Rogers, Superintendent of Plantations, at Amani [8]. His methods have been successfully adopted here and it would appear that either system is an easy way of grafting one variety of coffee upon another (*arabica* on *robusta*). Unfortunately with this method both scion and stock must be seedling material, an arrangement by which little ultimate gain can be obtained.

Cleft-grafting.—Most attention has been paid to this form of grafting, as by this method it is possible to graft clonal scion-material upon seedling stocks. Large numbers of grafts have been made in establishing a technique which gives a high percentage of successful unions. From observations made in the progress of this work the following conclusions have been made regarding the technique:

(*a*) The larger the stock and scion the easier it is to make a successful graft. Seedling stocks about 18–24 months old are much easier to graft upon than younger material.

(*b*) The stock should be cut just above or across a node and a cleft about 2 in. deep made between the buds.

(*c*) The scion is cut in the form of a wedge beginning on either side of a bud.

(*d*) The scion wood must be active at the time of grafting.

(*e*) The protection, which must be applied to prevent movement between the stock and scion until union has been made, should vary

according to the time of the year at which the graft is made. It has been found that the best time of the year for grafting at the Scott Agricultural Laboratories is during the cool, dry weather (June–October). In June, when sap flows freely from the stock, it will be advisable to bind the graft with gunny string only. Later in the season, at a time when there is little sap flowing and the weather is warmer, all cut surfaces, including the tip of the scion, should be protected with grafting wax.

(*f*) In all cases the whole graft should be protected for a period of about three weeks by covering it with a loose waxed-paper cover.

Grafting in the field upon old stocks.—All attempts at rind-grafting upon old stocks proved unsuccessful, so that other ways had to be exploited. The method adopted, which is proving successful, is that of grafting on sucker-growth encouraged from the base of the tree. When the sucker has obtained sufficient size and maturity it is treated in precisely the same manner as are seedling stocks in the nursery. The ordinary cleft-graft is made as described above and is waxed and covered with a paper cover as before. The tree may be stumped back to the sucker either before grafting or afterwards. If it is left until after grafting the natural shade thus formed will assist the newly made graft in its early days. Care must nevertheless be taken to stump before the graft makes too much growth or it will be drawn up and tend to become whippy. The growth of a graft on an old-established root-stock is remarkably rapid.

Sufficient work has been carried out to show that coffee can be reproduced successfully by asexual means in Kenya. It would not be wise, however, to recommend it for field practice before further experiments have been conducted to study the many problems involved in mass reproduction.

Among those which have already been forced to receive attention is the relationship between stock and scion and the effect of root-stocks of other *Coffea* species upon *C. arabica*. The behaviour of mature trees produced vegetatively deserves close attention and must be compared with trees raised from seed, both as regards variations in habit and in yield.

Acknowledgements

The writer is indebted to officers of the Departments of Agriculture in Kenya, Uganda, and Tanganyika Territory, and the East African Agricultural Research Station, Amani, for their advice and assistance at all times; to Mr. E. C. M. Green, Field Assistant, for his care of the field and breeding work; to Mr. L. Burton, Laboratory Assistant for the photographs reproduced; and to Mr. V. A. Beckley for kindly correcting the proofs of this paper.

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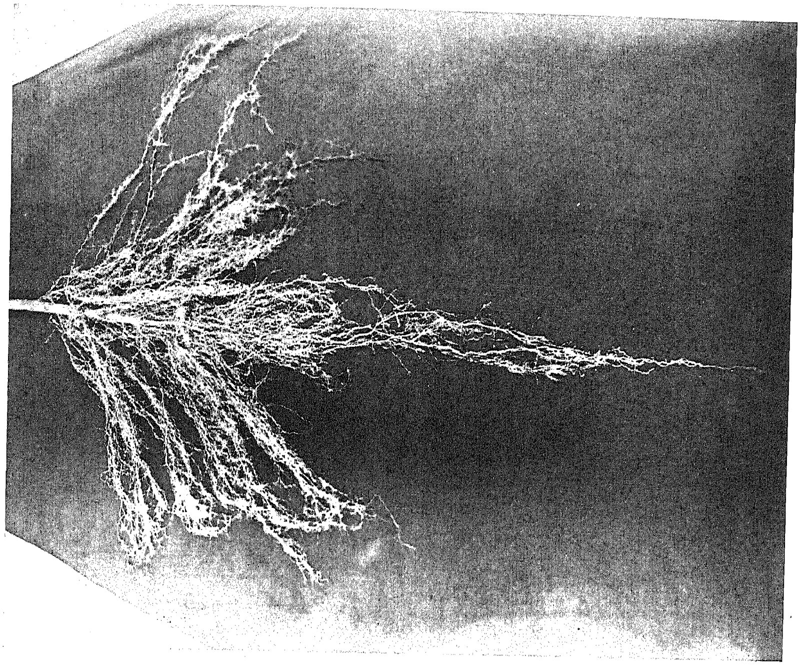

FIG. 2. Root-system of cutting
(Same age as seedling in Fig. 1)

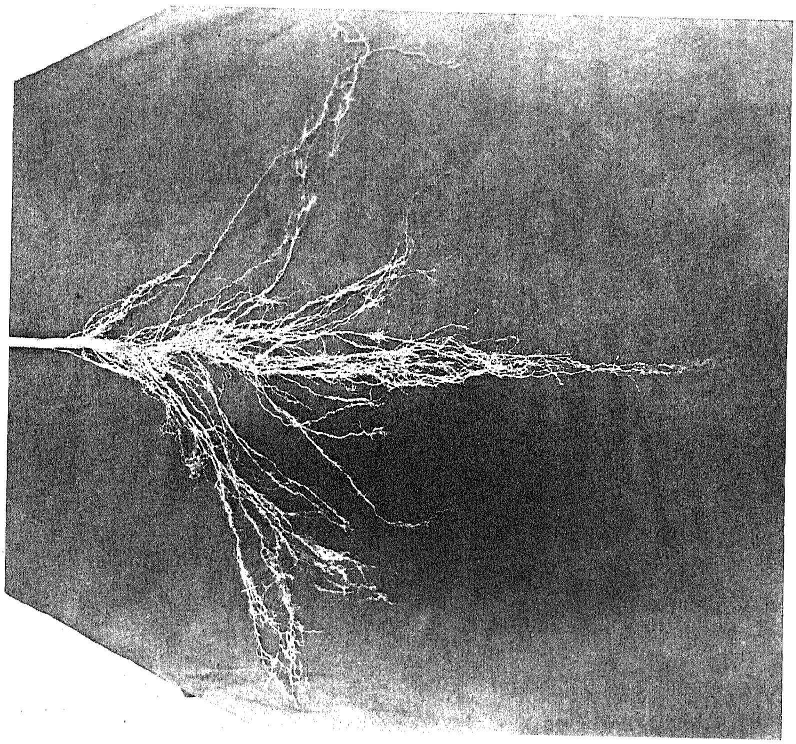

FIG. 1. Root-system of seedling coffee

FIG. 3. Seedling tree, $2\frac{1}{2}$ years old, in flower

FIG. 4. A vegetatively-propagated tree on its own roots, $2\frac{1}{2}$ years old, in flower

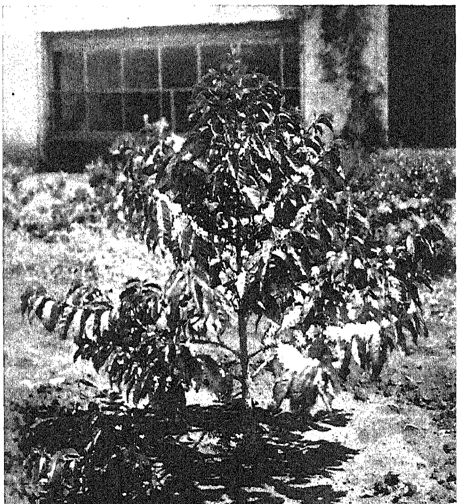

FIG. 5. A grafted tree on seedling stock, $2\frac{1}{2}$ years old, in flower

THE EFFECTS OF VARYING AMOUNTS OF ANIMAL PROTEIN FED TO WHITE LEGHORN PULLETS

Pt. I. THE INFLUENCE OF LOW-, MEDIUM-, AND HIGH-PROTEIN DIETS ON THE WEIGHT AND NUMBER OF EGGS[1]

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THE special interest now being shown in the weight of the eggs laid by individual birds, due to the greater economic value of the large egg, is reflected in the many experiments that have been made to study the various factors affecting both the number and weight of eggs that a bird lays. Studies are also reported of attempts to increase the weight of eggs above the normal size produced under normal conditions by a conditioned management and feeding of the hens.

Atwood [1] published data showing that liberally fed hens produced larger eggs than scantily fed hens, and unbalanced rations tended to reduce the size of eggs, i.e. the effect of normal and subnormal rations.

Nils Hansson [2] of Sweden, starting out from the standpoint that their extensive experiments with dairy cattle had given them definite results regarding the protein-requirements for production, used those results in computing rations for their studies (carried out simultaneously at three stations) on the protein-requirements of laying hens. He concluded that the optimum protein-content of a ration lies between 120 and 130 gm. digestible protein per feed-unit, provided the protein had a satisfactory biological value. He also observed that during heavy laying-periods, and also during colder weather, larger amounts of feed were necessary. Optimum protein rations caused a slightly better numerical egg-production than rations outside the optimum; the author, however, did not show the statistical significance of the difference. The various amounts of protein did not result in a difference in the average size of egg.

W. R. Graham, Jun. [3], in an experiment where the effect and value of various protein-supplements were compared, concluded that the differences in mean egg-weight that occurred were entirely without statistical significance.

Rice, cited by Curtis [4], showed that the number of eggs produced by a flock was positively correlated with the amount of feed consumed, and the fluctuations in amount of feed consumed were characteristic of the seasonal fluctuation in egg-weight.

Fangauf and Kallmann [5], in comparing two groups, one having a protein-carbohydrate balance of 1 : 3 and the other self-fed, showed that the self-fed birds varied the ratio according to the month of the year. During the experimental period November to July the self-fed group,

[1] Published by permission of the Principal, College of Agriculture, Stellenbosch, Union of South Africa.

during the months of highest protein-intake, balanced to 1 : 1·6; during March, April, and May to 1 : 3·1; and during July 1 : 4·7. No difference in egg-production of the two groups was observed. The normal group showed higher increases of body-weight.

Byerly, Titus, and Ellis [6] fed single-comb Rhode Island Red pullets with a basal ration to which was added 20 per cent. of protein-supplement in the form of feeds rich in animal- and vegetable-derived protein. They found a positive correlation of $r = 0{\cdot}226 \pm 0{\cdot}0347$ between percentage of protein in the diet and percentage production after first egg. They cite Kempster's [7] correlation between the same factors as $r = 0{\cdot}5179 \pm 0{\cdot}071$. The coefficient of correlation between percentage of protein in each diet and egg-weight is $r = 0{\cdot}339 \pm 0{\cdot}0317$. The conclusions from the above are that the percentage protein between the limits of 11 and 24 per cent. has a definite effect in that it increases the weight and number of eggs.

Parkhurst [8] found that varying amounts of protein in a ration, when the mineral-content remained the same, did not have any significant effect on the egg-size, and a complex protein was as ineffective as a simple one in increasing egg-size. Further extra amounts of skim-milk powder fed to crossbred pullets did not materially affect egg-size.

Material and methods of the experiment.—In the experiment described in this paper 60 South African White Leghorn pullets were used. They were divided into 3 groups of 20 each. Each group contained individuals of similar weight when the experiment began (Nov. 28, 1931).

All the birds were bred from four matings containing related blood lines and were hatched during July-August 1931. The pens were of the intensive type, the birds running on cement floors covered with oat-straw litter, which was replaced on the same day each week. These pens were covered on the one side with ½ in. mesh wire-netting from 2 ft. above the floor to the roof. The open side faced north-north-east, so that sunlight was admitted from shortly after sunrise until fairly late afternoon, even in winter. The College Farm is situated in the winter-rainfall area of the Union; also the poultry division is laid out on low ground at the base of a hill, consequently the birds experienced a considerable amount of morning mist and rain during autumn and winter. Trap-nests were provided in each pen and were visited approximately each hour during the main laying-period of the day. Each bird was retained in the experiment, and the eggs were recorded for 365 days from the date the first egg was dropped. The pullets were selected prior to reaching maturity. Three months after the commencement of the experiment three birds were culled which, although matured, had not begun to lay, whilst two other birds which had just started to lay died of apoplexy during a 'heat wave' experienced about the middle of February.

All eggs were weighed at 4 p.m. on the day laid to the nearest 1/32nd of an ounce. Eggs laid after this time were collected and weighed after the final trap-nest inspection towards evening. For all three groups a basal mash ration was used which consisted of bran, 40 lb., pollard, 35 lb., yellow mealie meal, 10 lb., Sussex oats, 12 lb., and bone-meal, 3 lb.; total 100 lb. To this basal ration 2½ per cent. by weight of blood-meal

was added to Group I (low-protein), 10 per cent. by weight to Group II (medium-protein), and 25 per cent. by weight to Group III (high-protein).

The grain fed to all three groups consisted of crushed yellow maize. Fresh separator milk was supplied each morning, and water, grit, shell, and charcoal were always available in the pens. The mash feed was fed in the dry state in self-feeding hoppers, which were standing in trays, so that any waste could be collected and deducted from the total feed consumed. These hoppers were left open from daylight until 3.30 p.m. At 4 p.m. the grain feed was fed in shallow trays, which were placed in the larger trays so that any material spilt might be collected. The birds were allowed access to this grain for about an hour. The separator milk was measured each morning before being supplied to the birds, and what remained at 3.30 p.m. was measured and deducted from the daily amount fed. The average analysis of the mash feeds used including the protein supplement was:

	Crude protein
	Per cent.
Group (1), low-protein	15·61
Group (2), medium-protein	20·31
Group (3), high-protein	29·06
Maize	9·50
Separator milk	3·39

Experimental results.—All the data obtained have been graphically presented and comprise graphs showing the following relationships:

1. Average amount in gm. of mash eaten per bird per month for each group.
2. ,, ,, gm. of grain eaten per bird per month for each group.
3. ,, ,, c.c. of milk drunk per bird per month for each group.
4. ,, ,, gm. of protein eaten per bird per month for each group.
5. The protein-carbohydrate ratio of feed and milk consumed each month.
6. Average number of eggs produced per group per month.
7. Average weight of eggs produced per group per month.
8. Average body weight of each group per month.

The amounts of feed eaten each month.—Figs. 1, 2, 3, showing the amounts of mash, grain, and milk taken each month and calculated per bird for each group, when these feeds are self-fed, clearly indicate that the amount of feed consumed depended almost entirely on the kind and composition of the feed itself and the month of the year.

Examining Fig. 1, one notices that the mash was taken by all three groups according to the amount of protein that it contained. Group I birds, which had access to a mash of a comparatively low-protein content, ate a larger amount than either Group II or Group III, whilst Group II again having been fed with a mash with a higher-protein content than Group I and a lower-protein content than Group III, ate more each month than Group III. The difference in amounts of feed eaten are also brought out in Table 1, showing the average amounts of feed eaten per bird per day for each group during the thirteen months that the experiment lasted.

Of special interest is the consumption of the mash during the various months of the year. Although there was a difference in the amount consumed by each group during each month, there was a striking similarity between the relative amounts consumed during each month during the

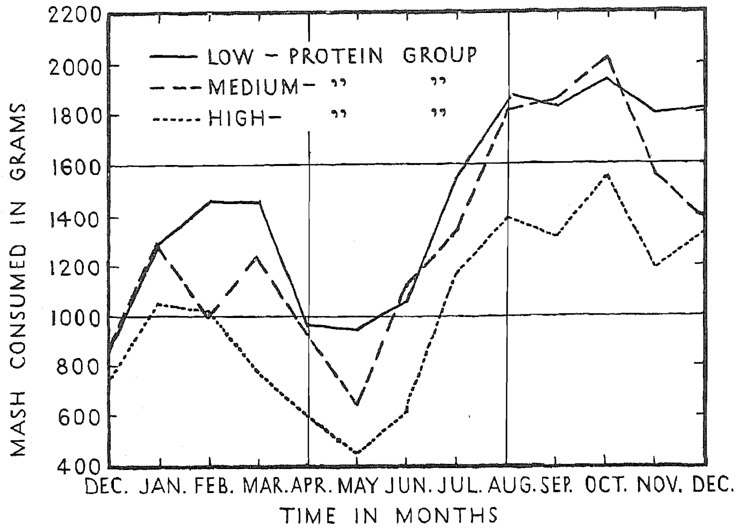

FIG. 1. Amount in grams consumed per bird per month of mash of low-, medium-, and high-protein content.

course of the year by the various groups. The parallelism of the three graphs is only broken badly during February, when for an unaccountable reason the medium-protein group consumed a quite disproportionately small amount of mash. No reason can be found for this deviation from the apparently normal consumption. Peaks of mash-consumption occur during the months of January, February, and March, and then again later in the year during August, September, and October. Low consumption, on the other hand, takes place during April, May, and June.

TABLE 1. *Average Amount of Feed taken per Bird per Day for each Group*

Group	*Mash* *Amount per bird per day*	*Grain* *Amount per bird per day*	*Separator Milk* *Amount per bird per day*
	gm.	gm.	c.c.
Group I . .	49·4	39·2	101·8
Group II . .	45·5	39·8	108·5
Group III . .	35·5	43·2	127·9

Fig. 2, which shows the amount of grain consumed during the thirteen months, portrays quite a different attitude of the birds to the grain. Comparatively, the amounts of feed taken are fairly similar, with a somewhat higher consumption by the high-protein group. The average

amounts of the whole experimental period, as shown by Table 1, are 39·2 gm., 39·8 gm., and 43·2 gm. for Groups I, II, and III, respectively.

In contrast with the mash-consumption there are no consistent fluctua-

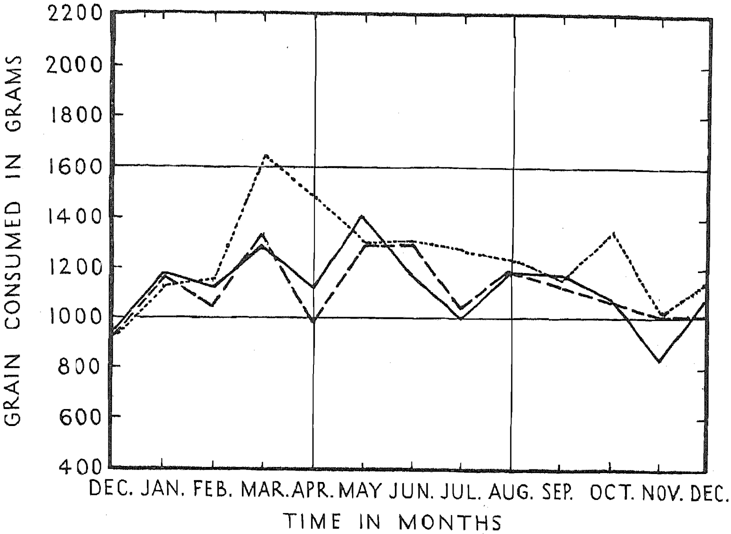

FIG. 2. Amount of grain in grams consumed per bird per month by the low-, medium-, and high-protein groups.

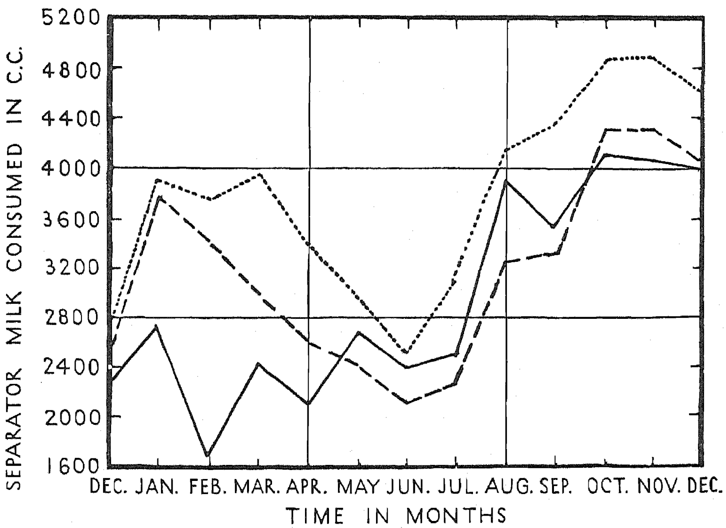

FIG. 3. Amount of separator milk in c.c. consumed by the low-, medium-, and high-protein groups.

tions during the various months of the year, with definite high and low peaks. During March and April and again in October the high-protein group shows a definite larger intake of grain. The tendency indicated is for the higher-protein group to take a larger amount of grain to balance

the mash containing the higher protein, whilst the low-protein group tends to take a larger amount of mash to balance the grain rich in carbohydrate.

There is certainly a tendency for the birds, when self-fed, to select their feeds in such a way that the resultant mixture consumed has neither a too high nor a too low protein-carbohydrate ratio.

When studying Fig. 3, viz. the separator-milk consumption per bird per month, one notices less consistent tendencies than in Figs. 1 and 2. Although birds in Group III consistently consume more separator milk than do those in Groups I and II, the graphs of the latter show no con-

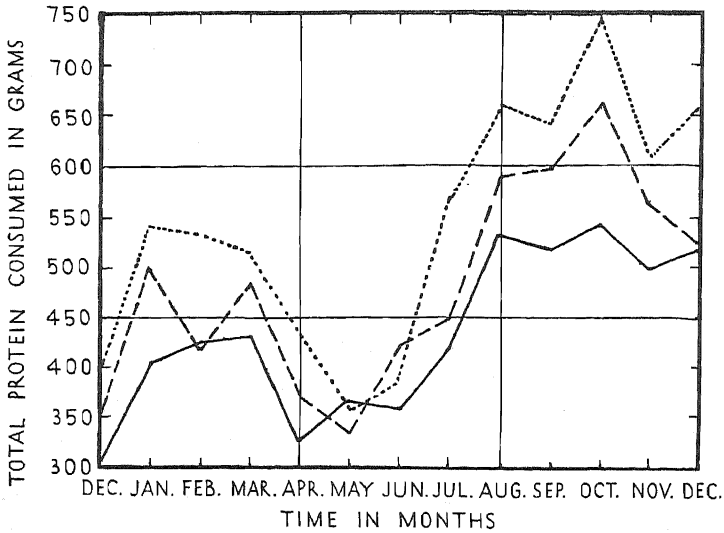

FIG. 4. Total amount of protein in grams of feed and milk consumed per bird per month of the low-, medium-, and high-protein groups.

sistent difference one way or the other. The average over the experimental period is 101·8 c.c., 108·5 c.c., and 127·9 c.c. for the low-, medium-, and high-protein groups.

Protein taken by the various groups.—Fig. 4 represents graphically the total amount of protein taken per bird, month for month, calculated from the analysis of the three kinds of feed provided.

Although all three feeds were self-fed and the birds showed a selective power to balance their rations towards a common protein-carbohydrate ratio, Fig. 4 shows that there was a definite difference between the amounts of protein taken by each group during the experimental period. The differences in protein-intake are largest during the months when the birds are consuming large amounts of protein, but during the months when comparatively small amounts are taken there is no significant difference. The average amount of protein taken per bird per month during the thirteen months for Groups I, II, and III are 434·8 gm., 481·8 gm., and 542·2 gm. respectively. Expressed as percentage differences the medium-protein group took 10·81 per cent. more protein and

the high-protein group 24·70 per cent. more protein than the low-protein group, whilst the high-protein group consumed 12·54 per cent. more protein than the medium-protein group (Table 2).

TABLE 2. *The Average Amount of Protein taken per Bird per Month and the Percentage Differences*

Group	*Average amount of protein per bird per month*	*Percentage difference in amounts between*		
		Groups I and II	*Groups II and III*	*Groups I and III*
	gm.			
Group I . .	434·8	10·81	12·54	24·70
Group II . .	481·8	..	..	..
Group III . .	542·2	..	..	..

Fig. 4, just as Fig. 1, shows that there is a striking similarity in the course of the curves of the three groups. All three follow one another very closely with the exception of the sudden drop during February depicted by Group II. High peaks of protein-consumption are evident during August, September, October, November, with the highest point in October. Lowest protein-consumption occurs during April, May, and June. As was to be expected, these graphs follow very closely those of the amount of mash eaten, as the mash being the largest source of protein of the feeds would most largely affect protein-consumption.

Protein, total carbohydrate ratio.—The total protein was calculated from the analysis of the various feeds, but in the absence of complete analysis the amount of carbohydrates was obtained by accepting existing analysis of the same kind of feed as being applicable to the consignments used in this experiment. Although the figures of total carbohydrates on which Fig. 5 is based have not the basis of exact chemical analysis, we are convinced that Fig. 5 is sufficiently correct to show the general trend of nutritive ratios, and from which tentative conclusions can be drawn.

Typical extremes of ratios have been selected and are presented in Table 3.

TABLE 3. *Ratios of Protein to Total Carbohydrates of Feeds taken during February, May, and October by the Three Groups, and the Average of the Whole Period*

Group	*Ratio of protein to total carbohydrates during*			
	February	*May*	*October*	*Whole period*
Group I . .	1 : 5·05	1 : 5·42	1 : 4·66	1 : 4·96
Group II . .	1 : 4·57	1 : 5·41	1 : 3·96	1 : 4·43
Group III . .	1 : 3·35	1 : 4·29	1 : 3·14	1 : 3·45

Examining Fig. 5, it is again evident that there are large differences in the ratios established by the various groups of birds. Only during May do Groups I and II approach one another. Table 3 shows the high and low ratios as occurring during February, May, October, and the average

over the whole period. This average value also shows comparatively large differences ranging from 1 : 4·96, 1 : 4·43, to 1 : 3·45 for the low-, medium-, and high-protein groups respectively.

The graphs are strikingly similar in form except during May and June, when Group II takes an apparently abnormal large amount of carbohydrates as against protein. Further, each graph can be divided into three definite periods, viz. a medium ratio during December, January, and February, a high ratio during March, April, and May, followed by a sharp fall during June and July reaching and maintaining a comparatively low ratio during the remaining months of August, September, October, November, with again an upward tendency during December. Grouped in seasons one could conclude that during autumn, spring, and summer there is a low carbohydrate-consumption in proportion to the protein-consumption, followed by a complete reversal during the winter months.

Influence of feeds on numerical production and egg-weight.—Fig. 6 shows the monthly production of eggs by each group, based on an even number of 18 birds in each group. It is immediately evident that whatever the difference in numerical production from group to group, the difference is not significant. Table 4, however, gives a better idea of the difference, but unfortunately also no true reflection for the following reasons:

TABLE 4. *Difference in Numerical Production calculated on an Even Number of Birds in each Group*

Group	*Eggs laid outside traps*	*Total no. of eggs per group*	*Av. no. of eggs per bird*	*Av. no. of eggs per bird excl. eggs laid outside traps*	*Diff. in no. of eggs per bird excluding eggs laid outside traps*
Group I	214	3,332	175·3	164·5±5·480	Groups I and II 10·1 ±8·216
Group II	113	3,248	182·3	174·6±6·121	Groups II and III 9·8 ±7·545
Group III	89	3,409	189·4	184·4±4·412	Groups I and III 19·9 ±7·036

Column 2 shows that a number of birds laid eggs outside the traps. This took place at the beginning of the experiment, when the hens had not yet become accustomed to the experimental pens, and when the attendant was still inexperienced. These eggs, together with the recorded eggs, are given in column 3 and divided by the number of birds in each group, as shown in column 4. There being no accurate method of attributing these eggs to the hens that laid them, only eggs recorded to the birds were used in calculating column 5. Because of the eggs laid outside the nests the averages shown in column 5 are lower than the correct average, and owing to the differences in these numbers Group I is affected more than Group II and the latter more than Group III. Consequently it was argued that should no significant difference be shown with the recorded eggs in favour of the higher-protein groups, certainly less would be shown if the eggs laid outside the traps could be allocated to the rightful owners.

As previously shown in Table 2 and Fig. 4, Group I consumed less protein than Group II, and the latter less again than Group III. No significant difference in number of eggs is apparent from Table 4 between

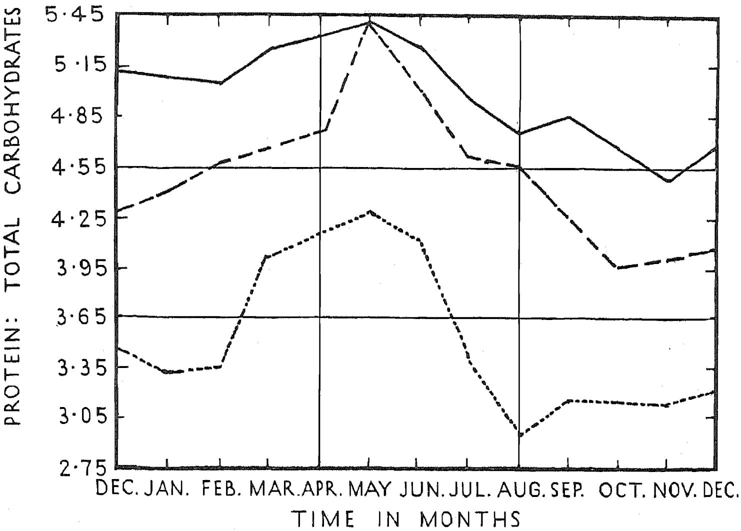

FIG. 5. Ratio of protein to total carbohydrates of total feed and milk consumed by each group each month.

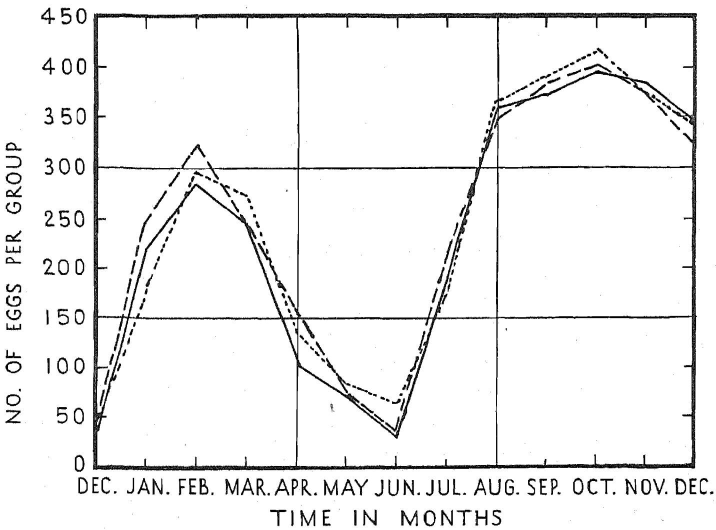

FIG. 6. The average number of eggs produced by the low-, medium-, and high-protein groups each month, calculated on an even number of 18 birds per group.

Groups I and II and between Groups II and III, as the difference in each case is less than twice the standard error of the difference. The outside trap eggs, if correctly recorded, would decrease still further, whatever significance there was.

Comparing Groups I and III, where there is a comparatively very large difference in protein-consumption between the groups, the difference in recorded eggs is significant. It is impossible to conclude, if the eggs were all correctly recorded, that there would still be a significant difference, as the averages per bird of the total eggs differ only by 14·1, whilst the difference of recorded eggs is 19·9. How the standard error would be affected by a correct recording is impossible to estimate.

The progressive increase in numerical production with increases of protein-intake would, however, suggest the conclusion that a protein-increase within certain limits carried out with a larger number of hens, of more uniform laying-capacity, would possibly increase their numerical production, although this fact is not conclusively proved by this experiment.

The curves showing the monthly production of eggs for the three groups (Fig. 6) reveal a most striking similarity. High and low peaks fall during the same months, and the same course is followed throughout by each curve. The seasonal effect is also definitely established. All three groups show high production during January, February, and March, i.e. in autumn, and again during August, September, October, and November, i.e. in spring and early summer. Low production occurs during the rainy winter months, April, May, June, and July.

Graphs 4 and 6, showing monthly protein-consumption and monthly production respectively, reveal such a marked correspondence that one can infer that as the protein-consumption increases over a certain period the numerical production increases over the same period. Keeping in mind that the natural influence to produce periodically has not been completely overcome by breeding and management, i.e. that it is still seasonal, and that the feed was available to be taken as desired, one can further conclude that the amount of protein consumed over a certain period depends wholly on the intensity of production over the same period. Feeding a mash *ad lib.*, as practised by all poultry-keepers, would seem to be a sound system of feeding and is strongly supported by the facts enumerated above.

Influence on average weight of eggs of each group.—Fig. 7, which shows average monthly weight of eggs produced by each group, is typical of the results published hitherto. The eggs produced by a pullet gradually increase in size until a maximum is reached, the peak being followed by a slight decrease in size. The differences are again not clearly evident from the graphs, and recourse must be taken to Table 5.

TABLE 5. *Average Annual Weight of Eggs produced by each Group and the Differences*

Group	*Average annual weight of eggs*	*Difference in average annual weight of eggs*
	gm.	gm.
Group I . .	53·749±1·072	Diff. Groups I and II 0·269±1·493
Group II . .	53·480±1·040	Diff. Groups II and III 0·406±1·408
Group III . .	53·886±0·913	Diff. Groups I and III 0·137±1·384

Column 3 shows no significant difference, in fact not even an approach to significance, between the average weight of eggs of each group. Unlike the difference in numerical production, there is no progressive increase in size of egg with the increased protein-consumption. Group II had a higher protein-intake than Group I, but has a lower average egg-weight, although the difference is not statistically significant. One can thus conclude that with the feeds used in this experiment an increased protein-consumption within the limits shown in Fig. 4 did not increase the mean weight of eggs.

Again, in comparing the average monthly weight of eggs with the

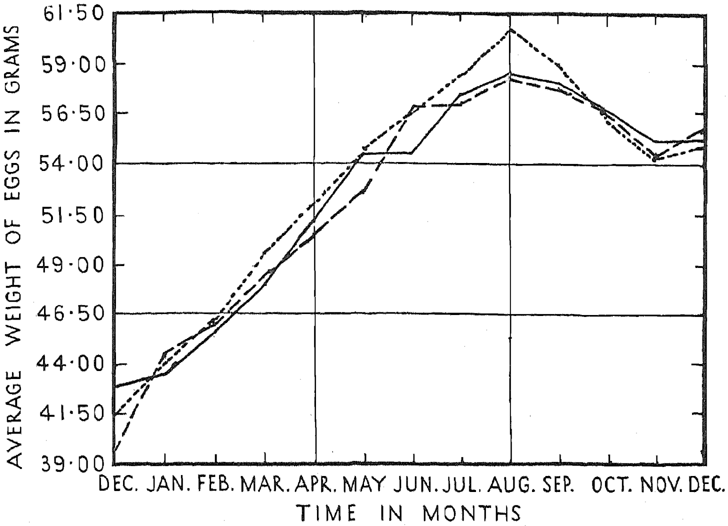

FIG. 7. The average weight of eggs each month of the low-, medium-, and high-protein groups.

monthly protein-intake, it is evident that the weight of the eggs increases independently of the amount of protein ingested. This is quite in contrast with the number of eggs, which shows a close relationship with the protein-consumption. For example, the protein-consumption during March is 47·7 per cent. higher than in May, yet the average weight of eggs laid during May was 10·6 per cent. higher than during March. Further, the average weight of eggs is highest during August, whereas the protein-consumption is the highest two months later, i.e. during October.

There is no correlation between the number of eggs laid during a certain month and the average weight of these eggs during the first year of production. Whilst the average weight of eggs increases in almost a straight line, the numerical production shows violent fluctuations, in fact during May and June there is almost a cessation of laying.

Increase in body-weight.—Fig. 8, showing the average weight of each group during each month obtained from a single weighing each month, is not as accurate as it would have been had weekly weights been averaged

to obtain the monthly weight. Being an average of a number of birds the general tendency can be shown.

No consistent differences are noticeable from the three graphs. Table 6 is therefore included to show the average weight over the experimental period and the difference.

TABLE 6. *Average Weight of Monthly Weighings for Three Groups*

Group	*Average weight of 13 monthly weighings*	*Difference in average weight*
Group I . .	1631·4±24·444	Diff. Groups I and II 26·3±31·27
Group II . .	1657·7±19·759	Diff. Groups II and III 9·4±32·74
Group III . .	1667·1±26·108	Diff. Groups I and III 35·7±35·77

A progressive increase in average weights is evident from Table 8, although no difference even approaches significance.

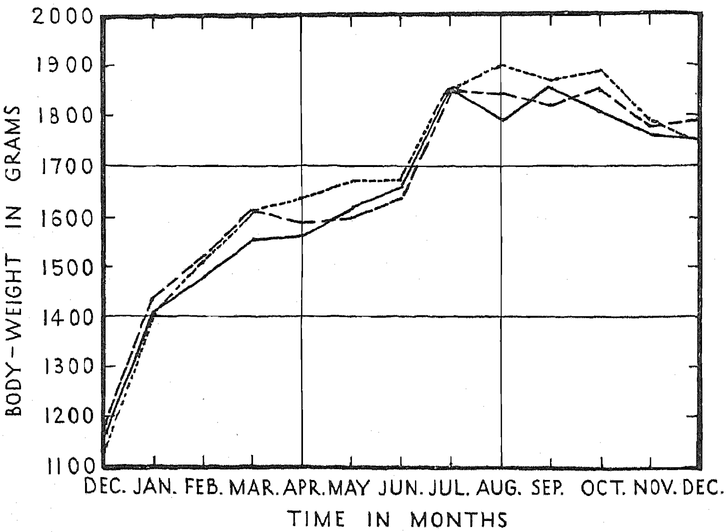

FIG. 8. Increase in average body-weight per bird per month of the low-, medium-, and high-protein groups.

Month for month there is a very close correlation between the average body-weight and the increase in weight of eggs produced (see Figs. 7 and 8), as will be more clearly shown in the second part of this paper. Following the course of these two graphs, they are fairly similar except during the winter months of April, May, and June, when there is only a very small increase in weight. This coincides with the lowest protein-consumption, as shown by Fig. 5.

Conclusions

1. The amount of mash consumed by three groups of pullets when self-fed mash, grain, and separated milk, depended on the protein-content of the mashes and on the season of the year.

2. The consumption of grain was fairly consistent throughout the year, especially when compared with the consumption of mash, which showed violent seasonal fluctuations.

3. Differences in milk-consumption were not consistent, except that the high-protein group consumed very much more than either the low- or the medium-protein group.

4. There was a definite difference in protein-consumption of the three groups. All fluctuated consistently during the various months of the year. There was also a definite difference in the ratio of protein to total carbohydrate of the feed consumed, but the birds showed a definite tendency to balance their rations to a common nutritive ratio.

5. A progressive difference in numerical production of recorded eggs was shown, although the only significant difference occurred between Groups I and III, i.e. groups having consumed the lowest and highest amounts of protein. This does not, however, exclude the possibility that had it been possible to attribute eggs laid outside traps to their correct owners, the difference would remain significant.

6. The various amounts of protein consumed did not cause any difference in egg-size approaching statistical significance. The same applies to differences of body-weight.

7. The numerical production each month in all these groups showed a very close relationship with the protein consumed during that month.

8. There was a very consistent increase in egg-size until August, almost amounting to a straight line when graphically represented. There seemed to be no relationship whatsoever between the amount of protein consumed and the number of eggs produced from month to month and the size of egg produced during corresponding months. The gradual consistent increase of egg-size was quite independent of environment and feeding, but closely related to increase in body-weight during the first year of laying.

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RICE-GROWING IN AUSTRALIA

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Introduction.—Although the production of rice in Australia is comparatively small, the industry has been so rapidly established that it has supplied the home requirements of Australia within the short period of six years since its inception. At the present time the production is being stabilized to meet the requirements of the Commonwealth and to allow of a small exportable surplus.

The success of rice culture in the San Joaquin Valley of California, where the soil, climatic, and economic conditions are very similar to those obtaining on the Murrumbidgee Irrigation Area, induced the trial of rice locally, and so successful were the trials that the industry became established immediately.

The growing of rice is very localized, being confined to the Murrumbidgee Irrigation Area in New South Wales. This does not mean to say that this is the only place in Australia suitable for the production of rice. The area on which rice could be grown as well and as cheaply as that at present used, could be very considerably extended. From the point of view of national economy, however, it is considered better to confine the area used for rice production to the present sowings, at any rate, for the time being. Any considerable extension of the area would only lead to an increase in the exportable surplus, which returns a lower price than that sold on the home market. The following table gives the area sown and production since commercial production began:

Season	*Area sown acres*	*Production tons*	*Average yield tons per acre*
1925–6	1,978	1,500	0·76
1926–7	4,772	4,887	1·02
1927–8	12,080	16,483	1·36
1928–9	14,321	23,228	1·62
1929–30	19,939	32,862	1·65
1930–1	19,990	26,084	1·30
1931–2	19,517	23,881	1·22
1932–3	22,787	36,000	1·62
1933–4	20,344	41,123	2·05

Soil and water.—The Murrumbidgee Irrigation Area is situated about 400 miles inland from Sydney and 300 miles from Melbourne, and the irrigation water is supplied by the Murrumbidgee River. The flow of this river is regulated by the Burrinjuck Dam, situated near Yass in the highlands, which has a storage capacity of 771,641 acre-feet.

The regulation of the flow of the Murrumbidgee by the dam is of service to private irrigation-plants, for stock, domestic and navigation purposes, flood-control, and hydro-electric generation, besides ensuring a

plentiful supply of irrigation water for the Murrumbidgee Irrigation scheme in drought years. Water is diverted into the main canal of the Murrumbidgee scheme at the Berembed Weir, about 200 miles downstream from the Burrinjuck Dam. Practically the whole of the Murrumbidgee scheme is gravitational and the cost of the water for rice-growing is 5*s*. per acre-foot which, being very low, has an important bearing on the economics of the rice industry.

The holdings on the area are of two types: horticultural holdings ranging from 20 to 50 acres on the lighter soil types, which are used for orchards and vineyards, and large holdings on heavy flat land, ranging from 200 to 400 acres of irrigable land, which are used for field crops like small grains, rice, grazing, &c. Prior to the cultivation of rice, these large holdings appeared to be difficult economic propositions. Dairying had not proved so successful as had been anticipated, and it was difficult to find remunerative types of crops. The introduction of rice-growing has entirely altered this, and these large holdings are now generally considered profitable enterprises.

Climate.—The climate of the district is of the Mediterranean type. The summer is hot and dry, but occasionally the monsoonal thunderstorms reach as far south as the irrigation area; nevertheless, most of the 16 in. annual rainfall occurs in the winter. The winter is mild, but radiation frosts occur. Being 200 miles from the sea there is a fairly marked diurnal temperature wave. The climate may be gauged by the type of fruits cultivated, such as stone fruit, grapes, and citrus. The rice is therefore grown during the summer months and only one crop is possible per year. It is sown as soon as the soil is warm enough to germinate the seed and all danger of frosts is past, i.e. early in October. To obtain maximum crops, the full length of the growing-season must be utilized, because, if seeding is delayed too long, the crop will not mature before the cold weather of the succeeding winter sets in. Harvesting operations begin early in April.

Cultural operations.—The cultural methods adopted have naturally been influenced by the farming methods evolved on the Australian wheat farms, where large areas are cultivated and where large implements are used. Owing to the economic conditions obtaining, the Australian farmer very early turned his attention to labour-saving machinery and implements, and ever since its inception Australian agriculture has been among the most advanced in the direction of mechanization. Whereas the cultivation of rice requires the expenditure of a very large amount of labour in most countries where it is grown, the labour involved in its cultivation on the Murrumbidgee Irrigation Area compares favourably with that required for wheat-growing. This fact, together with the large areas of heavy flat land and the abundant supply of cheap water, explains why rice can be grown under conditions of European standards of living in competition with that produced in the Orient.

The seed-bed for the rice is prepared by the use of large implements, similar to those used for the cultivation of wheat. Then the land is subdivided into basins by levees or checkbanks, the construction of which is a relatively simple and cheap operation. They are merely ridges

of soil at least 18 in. high, constructed by means of delvers drawn by horses or tractors. Owing to the flatness of the land, large rectangular basins, 3–8 acres in extent, can be used, there being no necessity for constructing the checkbanks on contours, so that the construction of them is not unduly expensive. Little or no grading is necessary, but the land is smoothed. The greatest variation of level of the land within a basin is a few inches only.

The original method adopted in germinating the rice was to flood the bays, drain, and then drill in the seed as soon as the soil was in a fit state. The soil was then kept moist by irrigation, if necessary, until the rice was about 6 in. high, when the flood-water was applied and maintained. This method is quite suitable for the first crop of rice grown on the land, as it is quite free from weeds, but if persisted in every succeeding crop becomes more weedy. The chief weed is barnyard grass (*Echinochloa crus-galli*, several varieties). Cumbungi (*Typha latifolia*), umbrella weed (*Cyperus difformis*), and other weeds that will grow in standing water, are also important.

In order to control weeds, the method of sowing has been modified. A good firm seed-bed is prepared and the seed is sown at a shallow depth in the dry soil. Water is then applied to wet the ground. Two or more waterings may be necessary to induce germination. A good germination of the rice and barnyard grass results. When the rice is just appearing above the ground, the flood-water is run on just sufficiently to cover the barnyard grass; this treatment drowns out the weed, but the rice survives.

When the rice has grown sufficiently, the depth of the flood-water is increased to about 6 in. and maintained at this depth until it is drained off a few weeks before harvesting. As the weather is cool, and the evaporation comparatively low at harvest time, the soil does not dry very quickly. The heavy rice soils are very sticky when wet, and the great problem in harvesting is the management of heavy implements on this sticky soil.

At first, various types of harvesting implements were used, including headers (combine-harvesters) and reaper and binders. It is difficult enough to draw implements over the sticky soil when the work done is only that of moving the implement, but when the driving-wheel of the implement must work the mechanism, the difficulties are very greatly increased. The ingenuity of the farmers and implement-makers has overcome this difficulty, and what is known as the 'rice-header' is now used. This machine is practically an ordinary wheat-header, modified to handle a crop yielding four to five times as much as wheat. It removes the heads of rice from an 8- or 10-ft. strip and threshes the grain, delivering the paddy rice into a bin. The mechanism is driven by an oil-engine, which is part of the implement. The whole is drawn along by either horses or a tractor, so that the wheels of the implement are not impeded by driving the mechanism, and the only pull on the drawbar is that necessary to move the implement along.

In this way the harvesting is completed very quickly. The expeditious removal of the crop is important, as any rains that fall during the harvesting lead to serious delays, making the soil more sticky, and thus increasing the cost of the operation and depreciating the value of the rice.

Crop rotations.—The industry has not been established long enough for any very definite schemes of rotation to have been worked out and adopted. Experience shows that on land growing rice for the first time, quite good crops are obtained with very indifferent soil preparation, so long as the seed is sown at the right time and one attends to such essentials as the correct construction of checkbanks.

It also appears that several good crops could be grown on the same land successively, but for one difficulty; and that is weed-control. Here, as in California, weed-control is the most serious problem of the rice-grower. Rotations and other cultural methods will largely revolve around the solution of this problem.

Under Australian conditions, it is difficult to get the land into a suitable condition to grow a second good rice crop immediately after a crop is harvested, so that the rice crop is often followed by a crop of wheat. After the rice crop is harvested in the autumn, a heavy stubble is left which is not in a fit state to burn until the summer. If it is desired to fallow before the wheat crop, the land is best ploughed the following winter and kept fallow through the summer, and the wheat sown the following autumn. Such a programme is illustrated as follows:

Rice sown October 1930.
Harvested April 1931.
Stubble burnt December 1931.
Ploughed June 1932.
Fallow until wheat sown.
Wheat sown April 1933.
Wheat harvested December 1933.
Rice sown October 1934.

With this scheme only two crops are obtained in the four years, and this is hardly sufficient. It is possible, however, to plough the land as soon as the rice stubble is burnt and have a short fallow, sowing the wheat the following April (1932), that is, a year earlier than in the above rotation. A crop of oats and peas could then be sown in April 1933, grazed off, and the land fallowed from December till the following October, when rice would again be sown. The programme would then be as follows:

Rice sown October 1930.
Harvested April 1931.
Stubble burnt and ploughed December 1931.
Fallow until wheat sown.
Wheat sown April 1932.
Wheat harvested December 1932.
Oats and peas for grazing sown April 1933.
Fallow December 1933 to October 1934.
Rice sown October 1934.

From the standpoint of the wheat crop, it is better to break the fallow in winter, but the difficulty is to do so after rice without losing a year. The aim is to get one crop of rice in four years.

Wheat is considered the crop next in importance to rice, and one advantage of following rice with wheat is that, although the rice soils are heavy and tenacious, they become wetted to a considerable depth by the continuous flooding of the paddy field. This soil moisture is largely available to the deep-rooted wheat plant and, provided superphosphate is added with the wheat seed and the nitrate-content of the soil is satisfactory, excellent wheat crops are grown after rice. The well-worked fallow ensures a high nitrate-level for the wheat crop. It is possible to obtain a second wheat crop and this is often done with advantage. The land can be grazed between the rice harvest and the fallow, so that it is being put to some use during this period.

It was at first thought that the growing of rice would seriously affect the structure of the soil: the heavy traffic on the wet soil during harvesting would inevitably puddle it. However, it has been found that the dense fibrous root-system of the rice in the surface-layer of the soil prevents this action, and, as a result, the growth of rice appears rather to improve the structure of the soil. Rice was found to have 82 per cent. of its root-system in the first 4 in. of soil [1].

Fertilizers.—Rice does not respond to nitrogen on land that is used for rice for the first time, but on land that has previously grown rice the crop responds to sulphate of ammonia. The usual dressing under these conditions is 2 cwt. per acre. More investigation and experience are required to obtain a better understanding of the conditions in which nitrogen is needed and when the supply of available nitrogen is adequate. There is no doubt that the nitrogen question will have a distinct bearing on future developments of soil management and cultural methods on rice farms.

The usual biological and chemical conditions of an agricultural soil are profoundly modified in the submerged rice soil, so that many practices evolved for other plants do not apply to rice. In particular, it is commonly found elsewhere that nitrates are unsuitable as fertilizers for rice. This was shown by Kelly [2] to be due to the conversion of nitrates to nitrites in the submerged rice soil and the harmful accumulation of the nitrites. However, sulphate of ammonia is used much more than nitrate of soda in Australia, owing to its price, so that for this reason alone sulphate of ammonia is the only nitrogen fertilizer used for rice.

Superphosphate does not lead to any increases in rice yields, but it is often mixed with sulphate of ammonia merely to assist mechanically the passage of the latter through the seed-drill. It seems somewhat surprising that rice does not respond to superphosphate on the Murrumbidgee Irrigation Area, as in the southern agricultural areas of Australia it is almost indispensable for the production of all other annual crops.

Varieties.—At the present time, practically all the rice grown is of the variety Coloro or selections of Coloro. Coloro was introduced from California and is a Japanese or short-grained variety. Recent selections of Coloro are later-maturing, but better yielders. With more experience in harvesting and with the machinery now used, early maturity is not so important, as late crops are harvested quite satisfactorily.

Colusa, a mid-season variety, was also grown but was discarded owing to its contamination with red rice. Wateribune was one of the first varieties tried, but proved too late in maturing. It was a particularly heavy yielder, and with the present improved methods of harvesting, it would fulfil a distinct requirement for late harvesting.

Seepage and drainage problems.—The seepage and drainage problems attending rice-growing on the Murrumbidgee Area are relatively small. When the irrigation area was first planned, a system of drainage-channels was designed, as well as a system of supply-canals and channels. Every farm was provided with a supply-outlet on the highest point of the irrigable land and was also connected to a drainage-ditch at the lowest point. The system of supply- and drainage-channels, therefore, finds an analogy in the circulating system of vertebrates. One difficulty that attended the introduction of rice-growing was the handling of large quantities of drainage-water when the rice lands were being drained in autumn, for when the drains were designed it was not anticipated that they would have to handle such large quantities of water. In many sections the drains could adequately cope with the water, but in others difficulties arose. In some cases, moreover, the drains from the rice farms passed through horticultural sections and a danger of seepage arose, owing to the large amounts of water in the drains in the lighter soil of the horticultural sections. Where supply-channels for rice fields passed through horticultural sections, the holding of the water at a high level in the channel continuously throughout the summer also constituted a menace.

Although the rice soils generally contain more salt than the horticultural soils, very little trouble with salt is experienced with them, as the movement of the water through the soil is very slow. It is on the more pervious soils of the horticultural sections that the accumulation of salt constitutes a serious problem. However, if it is attempted to grow rice on light soil, troubles due to seepage and salt are inevitable. For these reasons, the authorities exercise some control over the land that is used for rice-growing. There is some limit placed on the amount of land a settler can put under rice in any season, and rice-growing is only permitted on suitable soil, where the area sown to rice can be drained without menacing other holdings, or overtaxing the drains. Where rice farms adjoin horticultural farms, rice-growing is not permitted within a certain distance of the horticultural farm. This distance is often about five chains, but is dependent on the nature of the soil. In this way seepage from rice-fields into orchards is obviated.

Experiments and investigations.—The New South Wales Department of Agriculture has established a Rice Research Station on the Murrumbidgee Irrigation Area, where such questions as rice-breeding, fertilizers, rotations, and weed-control are being investigated.

The breeding-work consists of cross-breeding and selecting to develop more prolific varieties and to obtain uniform ripening. Attention is also being paid to the testing of long-grained varieties. The long-grained varieties at present available are too late in maturing for local conditions. The problem of the so-called 'sun cracking' is also receiving attention.

To date there is no serious disease problem or insect menace.

Marketing and controlled production.—As the production of rice in Australia is localized in one district in one State, the industry lends itself to organized marketing and the production can be controlled to a large measure. It is, therefore, not surprising that, with the present world vogue of control of production and trade, the commodity rice should be subject to regulation in Australia.

Legislative power exists in New South Wales for the control of marketing within the State of any agricultural commodity, if a poll of the producers of that commodity is in favour of the control. Rice is one of the commodities so controlled. There is a rice-marketing board consisting of five representatives of growers, elected by a poll, and two Government nominees. This board determines all questions relating to marketing and has wide powers. The Australian price is fixed by agreement with the millers and the area sown to rice is largely controlled. The control of the area sown is effected by the co-operation of the Irrigation Commission, a body which need only supply the quantity of water necessary for a certain acreage of rice.

An import duty on rice effectively prevents the importation of foreign rice. The Rice Board does not necessarily take advantage of this duty to increase the price of rice to the Australian consumer. It is claimed that the duty is used only to ensure the sale of home-grown rice, as without it millers could buy foreign instead of local rice, even though the prices were the same. It would be difficult to determine whether this is actually so or not, as overseas prices fluctuate and there are many considerations that complicate the issue. However, it is probable that the price of rice to the Australian consumer is very much the same as it would be if rice were imported duty-free.

In order to have the advantage of the protective duty, the industry has undertaken to supply Australian requirements of rice, and hence a surplus for export must be grown to allow for seasonal fluctuations in yields. The surplus rice is largely exported to New Zealand and the Pacific islands. The price realized for the exported surplus is below the Australian price, so that growers are paid for the rice delivered on the basis of the total pooled receipts.

The fact that the price received for the exported surplus is below the Australian price does not necessarily indicate that the Australian price is above world parity. The cost of shipping and other charges incidental to export are appreciable and these give the Australian product a certain natural protection; but they are a charge on exported rice, so that, disregarding any protective duty, the difference between the price received by the Australian grower for rice sold in Australia and that sold abroad should be twice the cost of shipping.

When the industry was first established a little difficulty was experienced from the deterioration of the paddy rice in store, owing to its excessive moisture-content. For this reason, rice is not accepted by the Rice Marketing Board unless it contains less than 17 per cent. moisture; if it exceeds this amount it must be stacked in the field to dry out. For the same reason the Rice Marketing Board has found it necessary to store the rice where it is grown and not at the seaboard.

Economics of industry.—It may seem strange that rice can be economically grown in countries like Australia and California that enjoy a high standard of living in competition with eastern countries where it is produced by coolie labour. A protective tariff is not the important economic factor concerned, as rice was profitably grown in Australia for a short time before the tariff operated. The fact is that very cheap labour is not always a great advantage. One man with a modern machine can accomplish as much as a large number of coolies with primitive implements.

There are also certain natural advantages enjoyed by the Australian grower. In eastern countries, rice is often the major or only crop grown, and all available land must be used. This fact often necessitates an enormous expenditure of energy in terracing and preparing the land. Water is often lifted by primitive methods that entail a very great expenditure of labour. Rice is frequently grown on the same land continuously and yields consequently fall.

On the Murrumbidgee Irrigation Area, the area available and under cultivation is very much greater than that necessary to produce the crop that it is at present thought economically worth growing, so that rice need only be grown on the same land about one year in four, and heavy crops can therefore be produced. The economic conditions obtaining, therefore, permit big yields being obtained over relatively large areas with a small expenditure of labour, so that the industry is placed on an equal footing with rice-growing in the Orient. The yields obtained, compared with those of other countries, are very high, the average being about 30 cwt. Three tons is regarded as a good yield, but yields of four tons (200 bushels) are not uncommon on land not previously sown to rice.

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THE RICE INDUSTRY OF BRITISH GUIANA

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With Plate 17

History.—Rice is not indigenous to British Guiana and appears to have been first introduced, during the occupation by the Dutch, from Carolina early in the eighteenth century. In the early years of the nineteenth century supplies from the United States were stopped, and favourable consideration was thereafter given to the extension of rice cultivation in British Guiana.

In 1901 a shortage of the Indian crop considerably reduced the supply for the local market and prices advanced. During the Great War grain shortage, transport conditions, and high prices provided an abnormal impetus and export figures rose sharply, to be followed by an almost equally rapid decline. After the War, supplies from India to the Caribbean again became regular; prices fell; there was growing dissatisfaction on the export markets with the quality of British Guiana rice and the Colony's exports continued to fluctuate violently from year to year on a downward trend until 1926 when a record low level was reached.

In 1927–8 the Department of Agriculture was reorganized and a vigorous advertising campaign, simultaneously with a Colony-wide distribution scheme of pure-line seed, was inaugurated. New export markets were sought, and the marketing system studied with the object of developing and modelling marketing methods to meet the requirements of the trade. To collect and disseminate information on behalf of the local rice-export trade, the writer, on Government's instructions, undertook a Trade Mission to Canada, in 1929, via the Caribbean colonies, which included Trinidad, Barbados, and the Lesser Antilles.

The rice industry of British Guiana may now be said to be firmly established and occupies the second position among the Colony's industries, sugar being easily first. The value of the export trade alone, even at the existing low prices, is well above the million dollar figure; in addition, the domestic trade is of considerable importance, as rice is a staple article in the local diet. In 1928 a new high level of exports was reached, and in each of the years 1930, 1931, 1932, and 1933 a new record was attained (Fig. 1).

In the development of the industry the East Indian section of the population, comprising over 40 per cent. of the whole, has played an important part. East Indians brought from India the knowledge and tradition of rice-growing, although, as has been indicated above, the earliest introductions of seed appear to have been made from the southern states of North America during the Dutch and French occupations.

Crop Production

The rice commercially cultivated in the Colony is lowland or aquatic in respect of environment. There are, in certain districts, two crops per

year; the autumn crop is the more important, and is sown from April to June. The spring crop, grown only in those districts where the water-supply permits, is sown from November to December. The varieties in general cultivation occupy, normally, about five months from the nursery stage to maturity.

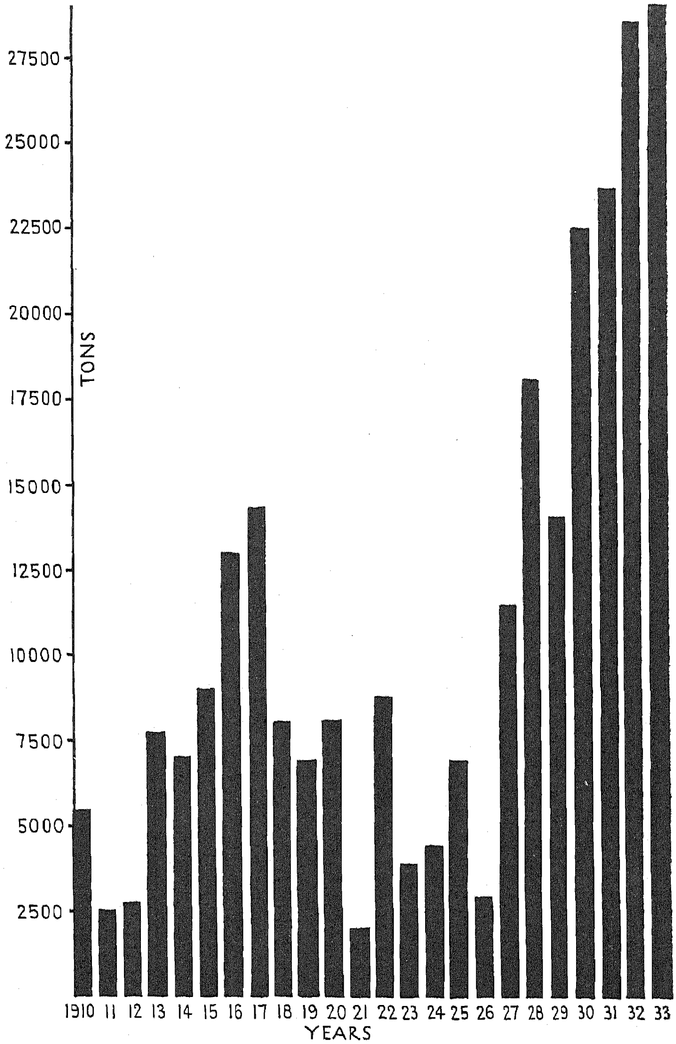

FIG. 1. British Guiana exports of milled rice, 1910–33.

Most of the rice is produced on the coastal belt and along the lower reaches of the several rivers. Before lands in these areas can be agriculturally occupied they must be empoldered[1] and an expensive drainage

[1] The coastal lands are low-lying and natural drainage is, in consequence, difficult. When an area is to be 'taken in', trenches surrounding it are dug on the three landward sides. The earth from these trenches is consolidated into dams which serve as a barrier

and irrigation system laid down. Much of this capital outlay has been provided for the production of sugar, a crop of relatively high financial returns per acre as compared with rice, which has, as a general rule, followed in the wake of sugar. Wherever, for one cause or another, areas have ceased to be cultivated for sugar, they have almost invariably been sown to rice. Further, it has now become the practice for sugar estates to encourage rice-growing on certain cane lands because, *inter alia*, it is accepted that the East Indian labour force is by this means more contentedly and more economically held together. Whilst Government has assisted village areas with drainage and irrigation problems—which are mainly connected with rice and other peasant cultivations—it is nevertheless true that capital invested in drainage and irrigation works by the sugar industry has benefited rice in the past and will continue to do so. There are, unfortunately, still large areas entirely dependent upon seasonal rainfall for rice production, which, under such circumstances, becomes a hazardous business.

A good average yield is 1½ tons of unhulled rice (padi) per acre, obtained when the seed is first sown in nurseries and the seedlings transplanted, whilst in some of the best areas that are growing pure-line seed exclusively, yields of 2 to 2½ tons per acre are not uncommon. Apart from considerations of quality, it has been shown in demonstration plots, in padi competition areas, and wherever careful comparisons can be made, that increased yields, according to conditions, of two to eight bags (140 lb.) per acre are obtained from pure-line seed of strains selected and distributed by the Department of Agriculture.

Table 1 gives some idea of the areas cultivated annually since 1924, together with estimated yields. It should be emphasized that these figures are to a great extent approximations, as there is much difficulty in collecting accurate figures bearing on an industry such as rice under the conditions existing in this Colony. The figures for yields do not necessarily bear a true relation to the area sown since the area actually reaped depends largely on weather conditions—shortage or excess of water. For example, 30 per cent. of the 1933 crop was destroyed by continuous heavy rains. Again, the acreage as given includes all types of cultivation—transplanted, broadcast, and self-sown (volunteer).

The cultural practices are not complicated. Ploughing, as in the East, is usually done by a pair of oxen, the plough being of the simplest type. If necessary there are two ploughings, followed by harrowing, clearance of weeds, and levelling. Levelling is important, because on its thoroughness depends the effective distribution of irrigation-water. Deep tillage is not necessary for rice, and although various types of mechanical implements have been introduced, their use has not become general. The present system is cheap and it persists.

The milling return is approximately 65 per cent. of clean rice to padi, the machinery used being simple and principally of the Engelberg type.

Parboiled rice is the type almost entirely produced in British Guiana,

against the influx of water from surrounding areas. A wall, or dam, is also erected on the fourth side in order to act as a barrier against sea- or, in some cases, river-water. Such an area is then said to be 'empoldered'.

and has obtained its name from the fact that the padi before milling is steeped in hot water, steamed and dried. The advantages claimed for the process are that the husk is more readily removed, the grain is toughened, and can be subjected to severe milling without great loss from breakage, and the parboiled product keeps better and longer than white rice.

TABLE I. *Production of Padi in and Exports of Rice from British Guiana*

	Padi		*Rice*	
Year	*Estimated Area*	*Estimated Production*	*Estimated Value of Exports*	*Exports (tons) expressed as percentage of 1927 exports*
	Acres	Tons	$	
1924 . .	40,272	42,100	312,587	39
1925 . .	39,890	38,403	523,964	60
1926 . .	49,445	49,899	218,146	25
1927 . .	50,427	59,748	723,871	100
1928 . .	55,560	61,144	1,114,147	157
1929 . .	63,441	72,096	876,407	122
1930 . .	63,482	64,252	1,090,385	195
1931 . .	83,492	78,424	1,060,339	205
1932 . .	87,941	84,783	1,187,871	248
1933 . .	87,125	63,524	1,062,470	253

Research and Extension Work

Pure-Line Development.—An important feature of the work with rice, following the reorganization of the Department, was the inauguration of a programme for the breeding and distribution of pure-line seed to growers throughout the country. Several varieties were collected from the areas under cultivation, but were identified in most cases only by their local names, their precise origin being obscure and pure strains non-existent. In fact, a chaotic condition existed.

It was therefore considered that a pure-line control station, where varieties might be maintained and whence pure seed could be distributed in sufficient quantity, must play an essential part in the expansion of the local industry and the improvement of the product. Careful organization is required in order to keep varieties unmixed in the districts under farm conditions, and even careful growers find that in two or three years padi deteriorates in quality, with red types in the ascendancy.

The purity of strains was established by making single-plant selections grown in 'progeny-row' plots. A regular routine is observed in obtaining pure seed for distribution and is represented in Fig. 2. This, or a similar procedure, is followed in the selection and improvement of many crops by agricultural workers.

This method of producing pure seed on a large scale refers to the selection and distribution of strains of established varieties. When new varieties are found which outyield the standard varieties, they are subjected to carefully conducted trials extending over three or more years.

Data are collected on their milling qualities and on their behaviour in different parts of the Colony before they are finally distributed for extension.

It may be mentioned that the private seed-farms are cultivated by selected growers as far as possible under the supervision of the District Agricultural Officers. To encourage the co-operation of the growers,

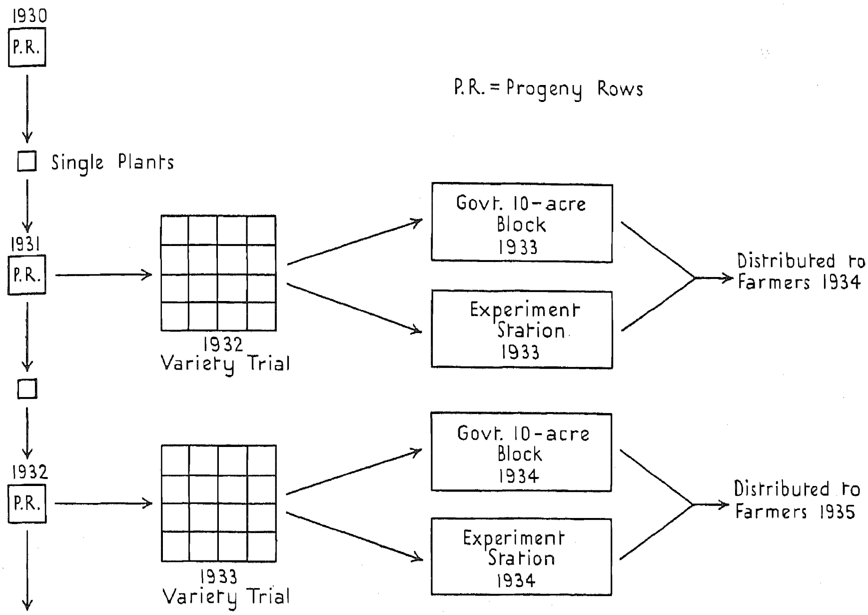

FIG. 2. Diagram indicating method followed for the production and distribution of pure-line seed.

padi competitions are run in the districts and valuable money prizes offered. In addition, the Department obtains the option of purchasing padi of a sufficiently uniform standard at a figure slightly above existing rates. The purchased padi is stored in seed barns centrally located in various rice-growing areas. Certificates signed by the Director of Agriculture are given to those growers who participate in the pure-line padi scheme and whose padi reaches the required standard.

A comprehensive programme of extension work was thus undertaken by the Department of Agriculture through its district staff. The effect was soon apparent; growers became 'pure-seed' minded, the demand for improved seed soon exceeded the supply, and the quality of the rice produced in this Colony was rapidly improved. Five prizes were awarded British Guiana for exhibits of commercial padi at the World's Grain Exhibition held in Regina, Canada, in 1933. The assistance received through the Colonial Development Fund helped generally in the achievements herein recorded, and specifically with the erection of a model rice mill and seed-padi barns, with the provision of the salary for a plant-

breeder, and with the establishment of a revolving fund for the purchase and distribution of seed.

Variety studies.—The policy of the Department is to introduce varieties from other rice-growing countries whenever such varieties appear likely to have qualities suited to local requirements, and a system of exchange with other countries has been adopted. Thus, varieties of the Carolina type are being grown under continued observation with a special view to the production of white rice. Certain other types have shorter growing-periods than the five months occupied by the varieties at present commercially cultivated; this character is being carefully studied, as a good-yielding, early-maturing type is a great desideratum at the present time, especially in areas where two crops are grown annually. Fig. 3 (Plate 17) shows the three padi types most widely cultivated in British Guiana.

Variety trials include studies of yield and other field characters, milling qualities and, in some cases, of cooking and food values. Spacing trials have been undertaken to determine the optimum planting distances in the case of a representative variety and investigations carried out to ascertain the effect of spacing on yield, panicles per clump, length of panicle, and weight of grain per clump. Observations on strength of straw, resistance to pests and disease, viability as affected by age of seed, and the effect of seed-selection by weight and size of grain, are also being made.

The breeding of new varieties is another interesting phase of this work, its principal object being the eventual development of strains which are ideally suited to local climatic conditions and cultural methods and possess suitable milling qualities. This branch of research involves the acclimatization of imported varieties, the creation of new strains by hybridization and subsequent careful selection during several generations from the various divergent progeny produced, the testing in the field of the different strains so evolved, and the evaluation of their respective properties.

The results of a recent yield trial are set out in the following table:

TABLE 2. *Variety Trials conducted by the Department of Agriculture*

	Demerara		*Essequibo*		*Berbice*	
Variety	*Padi lb. per acre*	*Order of Merit*	*Padi lb. per acre*	*Order of Merit*	*Padi lb. per acre*	*Order of Merit*
H 7	3,492	1	3,564	6	3,948	4
No. 79	3,352	2	4,074	1	5,208	1
No. 76	3,114	3	3,640	4	3,906	5
No. 75	3,095	4	3,850	2	3,696	6
Demerara Creole	3,080	5	3,808	3	4,200	3
Blue Stick	2,933	6	3,626	5	4,396	2
A 16·34	2,659	7	3,136	7	3,584	7
C 14·31	2,204	8	3,108	8	3,402	8
Significant Difference ($P = 0{\cdot}05$)	227		378		588	

12 replications of each variety. Plots $\frac{1}{80}$ acre each.

Brief notes on some of the more important varieties may be of interest and are given below. In Fig. 4 (Plate 17) the shape and comparative size of the grains may be seen.

Demerara Creole: Good yielding variety; long and somewhat weak straw; apt to lodge when ripe but grains do not 'shatter'; 'Seta Patna' type and slightly curved; percentage of breakage may be high in milling; husk, a light straw colour with tendency to produce awns; anthocyan pigmentation in leaf-sheath, apiculus and stigma; growth-period five months.

H. 7: Identical botanically with *Demerara Creole* and probably derived from it.

Blue Stick: Good yielding variety; does not lodge as much as *Demerara Creole* but grains 'shatter' freely; excellent milling qualities; husk light straw colour; no anthocyan pigmentation; growth-period five months.

No. 75: Grain of the 'Seta Patna' type with a decided curve; husk a dark golden brown colour; anthocyan pigmentation in leaf-sheath, apiculus and stigma; not favoured for general cultivation on account of excessive breakage in milling.

No. 79: A variant of *No. 75*; selected and improved by the Department; grain shorter than *No. 75*; milled rice almost indistinguishable from *Blue Stick* rice; husk golden colour with longitudinal brown furrows; anthocyan pigmentation same as *No. 75*; growth-period five months; proved to be a very successful variety.

Selected and improved strains of *Demerara Creole* and *Blue Stick* varieties are widely grown, whilst *No. 79* is being rapidly extended, already superseding *Demerara Creole* in certain areas. No other varieties are cultivated on a commercial scale.

Manurial and cultural investigations.—It has been determined that applications of fertilizers do not prove profitable on the soils of the experimental areas of this Colony, and it is possible that these soils are still sufficiently rich in the plant-nutrients required by rice to prevent any economic benefits being derived from the fertilizers applied. Nevertheless, a gradual decrease in yields has been noted from the experimental fields of the Georgetown rice station for a number of years and most of the older rice lands in the Colony are now showing evidence of declining yields.

A recent study by the Department of the results of padi manurial trials in other countries as compared with those in British Guiana, has revealed a highly significant correlation (coefficient of $-0{\cdot}9028$) between the yield from the unmanured plots and the yield obtained on manuring (stated as a percentage of the control yield). By the use of a regression equation involving the percentage increase and the common logarithm of the yield (lb. per acre) of the control plot, it seems possible to predict from the given yield of a field the probable increase to be obtained by manuring. Thus, in British Guiana, with the present prices of fertilizers and padi, it would appear not to be a profitable undertaking to manure any area which gives a yield of 2,800 lb. or over per acre. This point has been further elaborated in Rice Bulletin No. 1, 1933, of this Department.

It should be stated, however, that the experimental areas at the disposal of the Department give yields higher than this critical value, but further work is in progress on the whole question.

Trials with various types of implements, simply made to suit local practices, are being continued. Locally, the grain is generally threshed either by hand or by the treading of oxen, the local name for the latter operation being 'bull-mashing'. The Department's trials indicate that threshing-machines are economically justified, and demonstrations in this connexion are being made in the chief rice-growing districts of the Colony.

Control of pests and disease.—The chief field pests of rice are certain stem-borers (*Diatraea saccharalis* F. and *Scirpophaga albinella* Cram.). Although no effective measure of control has been evolved, there are certain agricultural practices, such as the ploughing in of stubble and flooding after reaping, which are found to assist. The Amazon fly (*Metagonistylum minense*) has recently been introduced, especially in connexion with the control of *D. saccharalis* in sugar-cane, and its effect on the control of the same pest in rice is awaited with interest.

The padi bug (*Mormidea poecila* Dall.) punctures the grain with its proboscis and absorbs the liquid contents. Such grains are therefore partly or entirely destroyed. The bug probably does less damage than *Diatraea*, but owing to its seasonal appearance, outbreaks always attract considerable attention. The only important control measures are the destruction of the conspicuous egg-masses and the collection of the adults with hand nets.

The chief pest of the stored product is *Calandra oryzae* L. The systems of padi and rice storage in the Colony do not permit fumigation to be used effectively. Investigations are therefore being made to discover some cheap and practical method for the control of the weevil. To discover such a measure is all the more difficult because the local uniform temperature throughout the year, and the relative humidity varying between 60 and 100 per cent., are so favourable to reproduction by this weevil that seven to twelve life cycles per annum are completed.

It is pleasing to be able to record that rice is little troubled by disease in this Colony.[1]

Trade

The grower usually sells his padi or the milled product to the miller. The miller, in some cases, exports directly, but more usually sells to recognized rice-dealing firms in Georgetown. Such a system, as may be anticipated, led to the shipping of an unstandardized product and to much dissatisfaction on the part of purchasers abroad of British Guiana rice. Government grading, under the direction of the Department of Agriculture, was instituted in 1930. A classification was made in which several grades were specified and defined with regard to colour and breakage, and it became compulsory for all shipments to be Government

[1] For complete details of the results of experiments and other investigations see Administration and Divisional Reports of the Department of Agriculture, British Guiana, 1928–32, and Rice Bulletin No. 1, 1933.

graded. Buyers received greater protection, and increased confidence in the product was established. Later, grading legislation was extended to include blending in order to ensure uniformity in each consignment of a specified grade.

More recently, progress has been made in bringing about co-operation among rice exporters. With this object in view, a Marketing Board was formed in 1932, the chief functions of which were to prevent the commodity from competing with itself on export markets and to promote concerted action in regard to price quotations. This Board's endeavours to bring about price stabilization have met with some success, although numerous difficulties are still being encountered, the chief of which is the practice of giving secret rebates by unscrupulous traders. The ultimate goal must be a centralized, co-operative marketing organization through which all export rice should be handled. To put this plan into operation is fraught with many difficulties at the moment, due to vested interests and financial entanglements extending over a long period of years, involving merchants, millers, landlords, and tenants. Any change must be gradual and must have the support of all parties concerned. A natural corollary is to provide credit through such a central organization for crop production, since the cultivators, under a system of land tenure imposed by the natural conditions on the coastal belt, are obligated in most cases to the landlord-miller, who in turn is dependent on the merchant-financier. A further complication arises in that rice is a food crop, extensively consumed in the Colony; it is subject to frequent price fluctuations dependent on supply and demand, and to severe competition from the cheaply produced Indian product in our natural markets, the neighbouring West Indian Colonies. Any central organization must, therefore, envisage ultimate control of the entire output in order to function efficiently and maintain a satisfactory balance between local consumption and exports. Further, any change from the present system may entail additional charges at present borne by individual merchants and exporters who deal in diversified commodities; these charges are now spread over and allocated to the several articles forming the stock-in-trade of the typical commission dealer to suit his own type of business. In the final analysis due regard must also be paid to the size of the industry, its possibilities of further expansion, and available export markets. The position, which is receiving the most careful consideration of Government, has been explained at some length lest it be thought a simple matter to bring the various interests together by legislative action.

Whilst marketing problems are now largely dealt with by the Marketing Board, the Department of Agriculture has steadily fostered and encouraged production concerning itself with all phases of development and actively participating in all measures calculated to the stabilization of the industry. The Department is co-operating with the Board, of which the Director of Agriculture is a member.

Another step forward has been the passing of legislation for the licensing and better control of the rice mills, especially in regard to building sites, sanitation, weights and measures used, and the keeping of proper records of dealings with rice farmers. It should be noted that rice-

milling in the Colony is carried out by a large number of small mills, of which there are about 200, the practice being for each proprietor of a rice estate to own and operate his own mill, thus enabling him to control his tenants' padi. The practice, though in many respects suited to the conditions existing in the Colony, leads to frequent complaints and dissatisfaction, and militates against centralization.

The research and extension activities broadly outlined in these pages were concurrent with significant development in the industry. An indication of the remarkable expansion which has taken place, in spite of low-price tendencies, may be obtained from Table 1, which gives the estimated production of padi and the exports of rice from 1924, expressed as a percentage of the 1927 exports. (See also Fig. 1.) Unfortunately, a setback (of a temporary nature only it is hoped) is being experienced

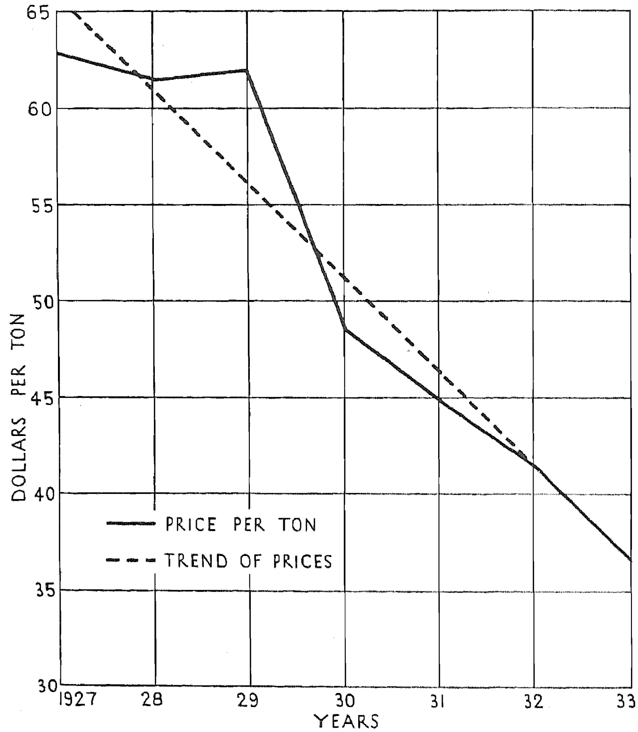

FIG. 5. F.o.b. prices and trend of f.o.b. prices of British Guiana rice, 1927–33.

during 1934 as a result of abnormal weather conditions. Floods that destroyed about 30 per cent. of the 1933 autumn crop (for export in 1934) were followed by drought conditions, which caused a reduction in area of the usual mid-year sowings.

As the rice output increased and the quality of the local product became standardized, new markets were gained. This is indicated by the increase in the number of markets to which British Guiana rice was

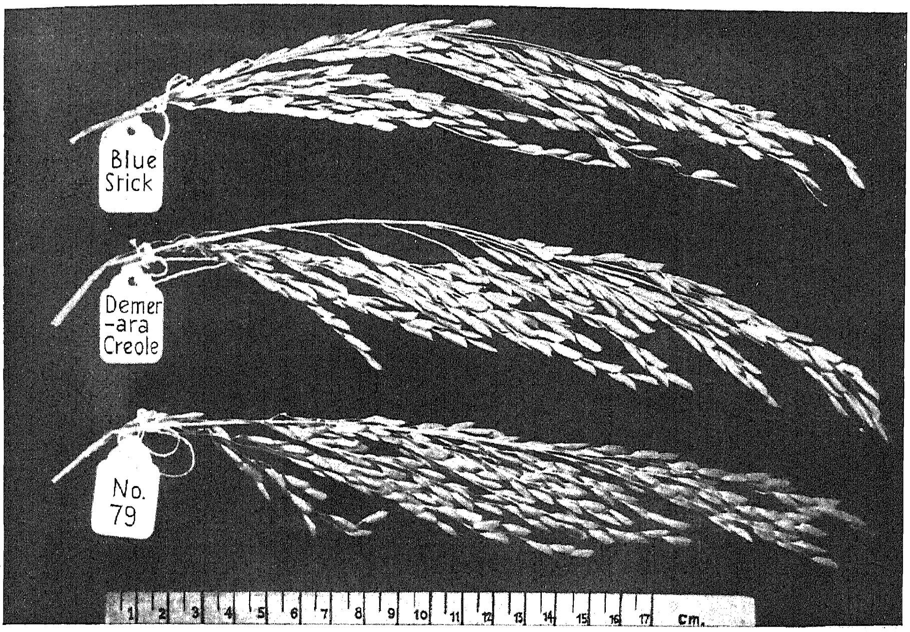

FIG. 3. Showing the three most widely cultivated types of Padi in British Guiana

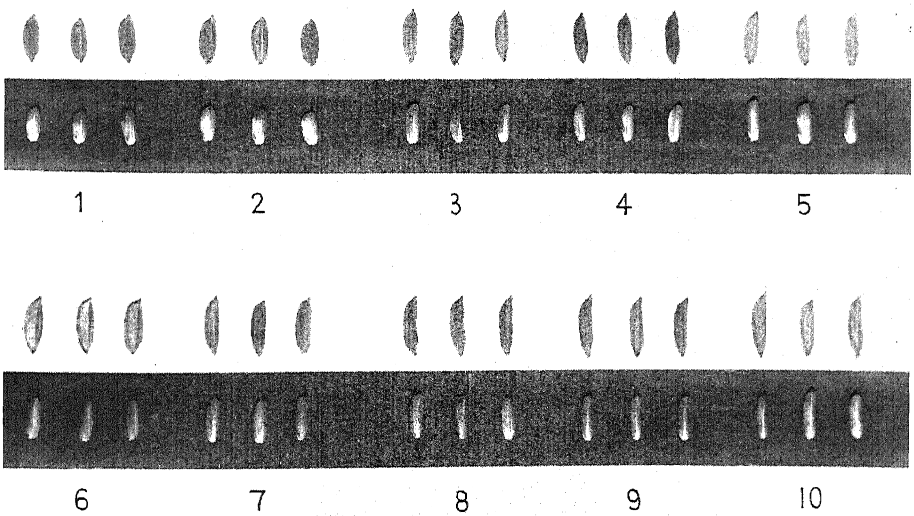

FIG. 4. Showing variation in shape and size of Rice Grains

1. Hope Barley. 2. C 14.31. 3. Blue Stick. 4. No. 79. 5. Ramcajara. 6. Carolina. 7. A 16.34. 8. No. 75. 9. Demerara Creole. 10. Kalyaman

shipped between 1928 and 1933. The bulk of the export trade, however, is with the Caribbean colonies, notably Jamaica, Trinidad, Barbados, and the French West Indies.

The economic conditions that have obtained during recent years in the industry are demonstrated in Fig. 5, from which it is seen that there has been an annual reduction of \$4.88 per ton in the f.o.b. price or a decrease of 10 per cent. per year from 1927.

These continually falling prices for the product have reached a point extremely discouraging to the grower, with little sign of improvement in the near future. Indeed, prices have now reached such a low level that any further decrease is likely to react unfavourably on the progress made in recent years, the nature of which has been indicated in this article.

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THE SOILS OF SCOTLAND

Pt. II. THE NORTH-EASTERN REGION

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THE north-eastern region extends from Stonehaven in the south, where the outliers of the Grampian mountains approach the coast, to the Orkney Islands in the north. On the east it is bounded by the sea and it merges gradually into the Highland region on the west. It includes the lower valleys of several rivers which drain the Highland region, together with the plateau of Buchan, the lowlands round the Moray Firth, the plain of Caithness, and the Orkney Islands. In places it is a very narrow shelf (the Highland region extending practically to the sea), but in Aberdeenshire it extends inland in some parts for 30 or 40 miles.

Climate.—The mean annual rainfall over most of the area ranges from 30 to 35 in. (762–889 mm.), but there are places along the Moray Firth where it is as low as 25 in. (635 mm.), and in certain of the more hilly parts it exceeds 35 in. (889 mm.). The distribution of the rainfall throughout the year is fairly even, but generally it is rather greater in the second than in the first six months, and the climate is much less humid than on the west coast.

Geology.—In considering soil formation and soil properties, it is convenient to consider the principal rock types in four main groups:

1. Basic-rock group, including igneous and metamorphic series, e.g. gabbro, norite, diorite, and epidiorite.
2. Acid-rock group, e.g. granite, granitic gneiss, and quartzose schist.
3. Slates and contact-altered schists.
4. Sandstones, conglomerates, marls, and shales of the Old Red Sandstone series. From a soil-forming point of view this is a very heterogeneous group.

Other types are found, but all the above groups occur extensively and cover the bulk of the area. The distribution of these rock types is shown in the geological map accompanying Part I of this paper.[1]

Most of the ground to an altitude of 1,000 ft. (305 m.) is covered with glacial drift of varying depth. This drift in most areas appears to have been influenced profoundly by the underlying rocks and to resemble them mineralogically. In texture it varies from a stiff boulder clay to sands and gravels.

Agriculture and Forestry.—The chief branches of agriculture in this region are the breeding and feeding of cattle and sheep, and the principal crops are rotational grasses, oats, and turnips. There is a considerable area of permanent grass, and other crops grown are potatoes and barley. In the dry sunny region near the Moray Firth some wheat is grown. A common rotation on the cattle-feeding farms is oats, turnips, oats, hay, and two years pasture grass.

Much of the land which is now under cultivation and in a high state of

[1] *Emp. Jour. Expt. Agric.* 1935, **3**, 177.

fertility was formerly covered with thin peat, and usually the laborious reclamation work was done by the small tenant farmers.

Most of the region has extensive woodlands, the area between the Moray Firth and Kincardine being the most densely wooded part of Scotland (17 per cent. of the total area in Nairn). The Scots pine is by far the commonest tree, and about two-thirds of the timber produced is from Scots pine, less than a tenth from hardwoods, and the remainder from larch, spruce, and other conifers. In the west and central regions of Scotland, on the other hand, spruces at present form the main crop species. The commonest hardwood is birch, followed by beech, oak, elm, and ash. The forestry system generally adopted is clear-cutting and replanting, but natural regeneration could be practised. Scots pine, larch, beech, and birch regenerate freely, but with oak and spruce regeneration is not satisfactory. Several exotic conifers, such as Douglas fir, Sitka spruce, and Japanese larch, are now being grown.

Soils.—The following soil groups are found in this region:

1. Podsolic soils.
2. Gley podsolic soils.
3. Gley soils and deep peat.
4. Brown soils.
5. Soils with undeveloped profiles.

Profile descriptions and analyses are given for a range of different parent materials. In the analytical work exchangeable calcium and magnesium were determined by leaching with neutral normal ammonium acetate (after Schollenberger), and exchangeable hydrogen by leaching with normal barium acetate and electrometric titration (after Parker). The results are expressed as m. eq. per 100 gm. soil. The clay fraction analyses were done on material obtained using a time-depth ratio of 8·6 cm./24 hours, with ammonia dispersion.

1 (*a*) *Podsolic soils over granites and granitic gneisses.*—These rocks cover an extensive area in the north-east of Scotland, and the soils which develop on the glacial drift derived from them have been very fully studied at Craibstone, the experimental farm of the North of Scotland College of Agriculture, which is situated 5 miles north-west of Aberdeen.

The composition of the mechanical separates of the surface-layer of a cultivated soil was investigated chemically by Hendrick and Ogg.[1] The conclusion reached was that the soil is composed largely of particles which have not undergone profound chemical weathering, and consists of the original granitic minerals mechanically ground, with only comparatively superficial chemical alteration. Attention was drawn to the large reserves of bases present in the coarser fractions and to the difference between these granitic drift soils and certain south of England soils derived from material which had undergone prolonged chemical weathering prior to the action of the present soil-forming processes. These conclusions were supported by the mineralogical analyses of Hendrick and Newlands,[2] who showed that Craibstone soil has a high content of undecomposed silicates containing large reserves of bases. The fine-

[1] *J. Agric. Sci.*, 1916, **7**, 458. [2] Ibid. 1923, **13**, 1.

sand fraction of a soil from Rothamsted, for example, was found to contain only 5 per cent. of minerals non-quartz, whilst that from Craibstone contained 30 per cent.

The absorption of sulphate of ammonia by Craibstone soil and its various fractions was studied and a comparison with powdered granite was made by Ogg and Hendrick.[1] Later, an examination was made by Hendrick and Newlands[2] of some aspects of the replacement or exchange of bases in the surface cultivated soil by ammonium chloride solution. The relative proportions of exchangeable divalent and monovalent bases found were as follows (per cent.): calcium 85·02, magnesium 8·11, potassium 2·18, and sodium 4·68. Lysimeter studies have been carried out by Hendrick and Welsh on a cultivated soil at Craibstone for the past seventeen years, but this work will be dealt with in a later section of this paper.

Detailed profile studies, including ultimate chemical analyses, were carried out by Stewart[3] on an uncultivated area of gravelly morainic drift, and on a cultivated area of heavier drift. Stewart concluded that the uncultivated soil was an iron humus podsol. He found from mechanical analyses that the carrying down of fine material from the surface into the lower layers had proceeded only to a slight extent, but the chemical examination showed a marked concentration of sesquioxides in the B horizon. The cultivated profile showed little evidence of podsolization, and Stewart suggested that it was at one time podsolized but that cultivation and treatment had brought about a regradation of the profile. The uncultivated profile at Craibstone West Woods may be taken as an example of a podsolized soil on morainic sands and gravels:

Parent material: Sands and gravels, derived mainly from granites and gneisses.
Topography and elevation: Undulating morainic region: 420 ft. (128 m.).
Rainfall and drainage: 34 in. (864 mm.); free.
Vegetation: De-afforestated area, now replanted. *Calluna vulgaris* dominant, *Vaccinium Myrtillus*, and *Erica cinerea*.

(1) 0–2 cm.	Surface litter.
(2) 2–8 cm.	Dark brown to blackish layer with white specks of SiO_2; slightly laminar in structure; plant-remains decipherable and roots abundant.
(3) 8–18 cm.	Sandy loam; light grey mineral particles and brown organic material; structureless; plastic but gritty; plant-remains decipherable and roots present.
(4) 18–30 cm.	Light brown sandy loam; friable and permeable; organic matter well decomposed; roots present; contains scattered vertical intrusions of surface material.
(5) 30–55 cm.	Dark brown, coarse, sandy loam; friable but more compact than (4); organic matter well decomposed; roots stop sharply at bottom of this layer.
(6) 55 cm.+	Yellowish-fawn sand and gravel with horizontal rusty streaks: cemented but quite friable when broken; stones increase in quantity and size with depth.

[1] *J. Agric. Sci.*, 1920, **10**, 333. [2] Ibid. 1926, **16**, 584. [3] Ibid. 1933, **23**, 73.

TABLE 1. *Analyses of Podsolized Soil (over Granite and Granitic Gneiss), Craibstone, Aberdeenshire*

Layer	(2)	(3)	(4)	(5)	(6)
Depth (in cm.)	2–8	8–18	18–30	30–55	55+
pH	5·2	4·5	4·9	5·0	5·8
Loss on ignition %	44·4	12·0	13·8	15·8	4·6
Exchangeable Ca (m. eq.)	13·9	1·5	0·6	1·2	0·4
,, Mg ,,	4·2	0·8	0·8	0·4	0·3
,, H ,,	26·3	14·5	14·2	14·2	4·0
Clay %	..	5·7	10·4	5·4	1·5
Clay fraction SiO_2/R_2O_3	..	2·46	1·44	0·91	1·04
,, SiO_2/Fe_2O_3	..	18·42	4·71	3·19	5·39
,, SiO_2/Al_2O_3	..	2·84	2·07	1·28	1·29

The cultivated profile from South Meethill field, Craibstone (adjoining the lysimeters), was developed on a drift of somewhat heavier texture overlying the same type of rock. It has long been under cultivation:

(1) 0–20 cm. Dark grey-brown loam: somewhat plastic, organic matter well decomposed; earthworms present.

(2) 20–45 cm. Yellowish-brown loam with some rusty brown and greyish mottling; variable in thickness and no sharp line of demarcation from layer (3).

(3) 45–125 cm. Brownish boulder clay, with dark grey and blackish mottling due to schistose fragments; becoming more stony with increasing depth.

TABLE 2. *Analyses of a Cultivated Soil (over Granite and Granitic Gneiss), Craibstone, Aberdeenshire*

Layer	(1)	(2)	(3)
Depth (in cm.)	0–20	20–45	45–125
pH	5·6	6·3	6·3
Loss on ignition %	8·8	3·8	3·5
Exchangeable Ca (m. eq.)	6·0	5·2	4·3
,, Mg ,,	1·2	1·9	2·1
,, H ,,	10·9	3·4	3·1
Clay %	10·1	13·1	13·6
Clay fraction SiO_2/R_2O_3	2·00	2·09	2·18
,, SiO_2/Fe_2O_3	8·62	8·36	8·09
,, SiO_2/Al_2O_3	2·60	2·90	2·98

From the clay-fraction analyses of these two soils it is evident that the uncultivated profile from West Woods is definitely and fairly strongly podsolized, whilst the cultivated soil from South Meethill field, less than a mile away, resembles a brown soil. Morphologically, however, the cultivated soil shows some evidences of podsolic origin, and it seems probable that its appearance and composition have been altered through cultivation and treatment. It is unlikely that it was ever as strongly podsolized as the lighter-textured West Woods profile.

Many of the cultivated profiles on granitic drift in this region, however, retain the podsol characters both morphologically and chemically. The typical glacial drift, although comparatively light in texture, is often firmly compacted, and in the profile, at a depth of about 40–70 cm. (the depth and thickness of the layer vary a good deal) there is frequently a layer which appears to be cemented as well as compacted. Even when moist it is difficult to dig, and when dry it is almost as hard as a road surface. Portions broken out of this layer crumble readily in the hand, but few roots penetrate into it.

1 (*b*) *Podsolic soils over slate.*—An extensive area of slates occurs in Aberdeenshire, and the soils over this material are usually podsolic or gley podsolic. Much of the land is at a fairly high elevation. Below 1,000 ft. (305 m.) cultivation is common, although considerable areas are under long rotations and used chiefly for grazing; above 1,000 ft. it is rough grazing. In the region studied the glacial drift is often thin.

Two profiles are described[1] from Broom Hill, Wells of Ythan, Aberdeenshire. Both are on glacial drift over slate, at an altitude of 850 ft. (259 m.), and the annual rainfall is about 35 in. (889 mm.). The uncultivated profile is from a thick wood of Scots pine, with occasional beech near the edge.

Uncultivated profile

(1) 0–2 cm.	Layer of litter consisting chiefly of pine needles and occasional mosses.
(2) 2–5 cm.	Grey, fine, gritty sand; loose, friable, and structureless; many roots.
(3) 5–26 cm.	Light grey sandy-loam; fairly compact with tendency to platy structure; patches of loose darker grey material, especially around roots.
(4) 26–28 cm.	Compact layer containing hard-pan.
(5) 28–47 cm.	Light brown silty loam, with many patches of blackish-brown organic material around roots; ochre spots; roots abundant; pieces of slate present, but less frequent than in layer (3).
(6) 47 cm.+	Light yellow-brown silty sand between shattered slate; hard and compact; occasional roots penetrate.

TABLE 3. *Analyses of a Podsolized Soil (uncultivated), over Slate, Wells of Ythan, Aberdeenshire*

Layer	(2)	(3)	(4)	(5)[1]	(5)[2]	(6)
Depth (in cm.)	2–5	5–26	26–28	28–37	37–47	47+
pH	4·6	4·6	..	4·9	4·8	5·1
Loss on ignition %	..	12·7	11·4	9·5	8·4	3·9
Exchangeable Ca (m. eq.)	13·4	0·9	..	0·9	0·7	0·5
,, Mg ,,	3·7	0·4	..	0·4	0·1	..
,, H ,,	48·3	23·8	..	17·9	17·3	6·4
Clay %	..	14·2	13·5	12·3	13·4	6·3
Clay fraction SiO_2/R_2O_3	..	1·56	0·90	1·10	1·35	1·46
,, SiO_2/Fe_2O_3	..	7·28	2·09	3·16	4·92	6·23
,, SiO_2/Al_2O_3	..	1·98	1·58	1·68	1·85	1·91

[1] Unpublished data supplied by Mr. W. H. Williams.

Cultivated profile

(1) 0–26 cm. Dark grey loam with fragments of slate; fairly compact and roots abundant.

(2) 26–36 cm. Dark yellow-brown silty loam; pieces of slate occur; roots occur but stop at this layer.

(3) 36–49 cm. Similar to layer (2), but contains thin layer of iron pan at about 39 cm.

(4) 49–58 cm. Light yellow, fine, silty loam scattered through shattered slate; very compact.

TABLE 4. *Analyses of a Podsolized Soil (cultivated), over Slate, Wells of Ythan, Aberdeenshire*

Layer	(1)	(2)	(3)	(4)
Depth (in cm.)	0–26	26–36	40–49	>58
pH	5·7	5·7	5·7	5·7
Exchangeable Ca (m. eq.)	4·0	1·7	1·7	2·3
" Mg "	0·6	0·4	0·5	0·3
Clay %	16·0	12·1	21·7	19·5
Clay fraction SiO_2/R_2O_3	2·34	1·76	1·79	1·92
" SiO_2/Fe_2O_3	16·59	13·20	6·16	8·01
" SiO_2/Al_2O_3	2·73	2·03	2·52	2·52

Both of the above profiles show marked evidence of podsolization, and from the differences in pH the cultivated soil would appear at some time to have been limed. The cultivated soil has not been profoundly altered, however, as in the case of the cultivated soil at Craibstone.

1 (*c*) *Podsolic soils over the Old Red Sandstone formation.*—The Old Red Sandstone formation occurs extensively in the north-eastern region, and on it is found some of the best agricultural land. As has already been mentioned, this formation provides a wide range of parent materials for soils. Muir has studied several of the soil types, in his survey of the Teindland State Forest.[1] The forest occupies the north-east portion of Findlay's Seat, a hill with an altitude of 860 ft. (262 m.) near Elgin, in Morayshire. He describes three main groups of soils:

1. Normal podsols on fluvio-glacial sands and gravels.
2. Peaty gley podsols with hard-pan on boulder till.
3. Peaty gley soils on boulder till.

The main conclusions reached by Muir regarding the normal podsols at Teindland are as follows:

1. Morphologically, the soils showed evidence of strong podsolization; according to the classification used in Scandinavian countries they would be grouped as iron podsols. The A_1 layer, where present, was never more than a few millimetres thick, and there was a very marked platy structure in the A_2 horizon of two of the profiles examined. The humus-accumulation layer (B_1) was found in all the profiles, but only in one was there any iron pan below this layer.

[1] *Forestry*, 1934, 8, 25.

2. Mechanical analyses brought out clearly the removal of the clay complex from the upper and its deposition in the lower layers.
3. Clay-fraction analyses showed there had been considerable leaching of both iron and alumina from the upper layers and deposition in the lower layers; alumina, except in one profile, was carried down much farther than the iron.
4. According to the ultimate analyses, most of the main constituents are at a maximum in the lower part of the illuvial horizon, whilst according to the clay analyses, the maxima occur in the upper and middle parts of the illuvial horizon.
5. Except in the organic horizons, the content of exchangeable bases was extremely low, and the pH of the illuvial horizon was generally about 4·5. Further work has shown that there is a marked decrease in the exchange-capacity of the eluvial horizons as compared with the illuvial, probably due to the breaking down of the adsorption-complex.

2. *Gley podsolic soils*.—This would appear to be the commonest type in the areas examined up to the present, and in some localities where it occurs over a comparatively light-textured drift, the gleying seems to be due to the compactness of the drift.

2 (*a*) *Gley podsolic soils over granites and gneisses*
Location: Craigiebuckler, Aberdeen.
Parent material: Boulder clay, derived mainly from granites and gneisses.
Topography and elevation: Gentle slope to flat; 300 ft. (91 m.).
Rainfall and drainage: About 32 in. (813 mm.); slightly impeded.
Vegetation: Cultivated ground.

(1) 0–25 cm.	Dark grey-brown crumbly loam; fairly stony.
(2) 25–30 cm.	Rusty and humus-stained loam; no structure, stony, occasional soft concretions; roots usually penetrate along humus-stained channels.
(3) 30–50 cm.	Brown and grey stony loam; fairly compact; roots penetrate to about 60 cm.
(4) 50–115 cm.	Brownish boulder clay; somewhat gritty and sandy; stones frequent; compact.

TABLE 5. *Analyses of Gley Podsolic Soil (over Granites and Granitic Gneisses), Craigiebuckler, Aberdeen*

Layer	(1)	(2)	(3)[1]	(3)[2]	(4)[1]	(4)[2]	(4)[3]
Depth (in cm.)	0–25	25–30	30–40	40–50	60–70	80–90	105–115
pH	5·7	5·8	5·9	5·6	5·5	5·7	5·7
Loss on ignition %	12·9	6·4	3·9	3·3	3·1	2·2	2·2
Exchangeable Ca (m. eq.)	7·2	5·1	2·2	2·3	2·7	2·5	2·7
,, Mg ,,	1·5	1·0	1·0	1·1	3·0	2·7	2·6
,, H ,,	13·0	8·2	5·4	5·5	4·5	2·8	3·4
Clay %	14·3	15·1	15·5	20·0	23·5	13·9	18·3
Clay fraction SiO_2/R_2O_3	1·41	1·28	1·66	1·82	1·99	1·97	1·95
,, SiO_2/Fe_2O_3	7·81	5·71	7·22	7·87	9·04	9·59	10·36
,, SiO_2/Al_2O_3	1·71	1·66	2·15	2·37	2·55	2·49	2·40

This soil has doubtless been considerably modified by cultivation, liming, and manuring, but the podsol characters are still evident. Gleying in this case is comparatively slight.

2 (*b*) *Gley podsolic soil over slate*
Location: Hillhead of Chapelton, Glens of Foudland, Aberdeenshire.
Parent material: Glacial till over slate.
Topography and elevation: Undulating upland; 900 ft. (274 m.).
Rainfall and drainage: 35 in. (889 mm.); fair.
Vegetation: Old pasture; very mossy.

(1) 0–15 cm.	Dark brownish-grey, gritty, stony loam; small crumb structure; roots and worms numerous.
(2) 15–40 cm.	Rusty-brown, gritty, stony loam; colour becomes lighter with increasing depth; structureless; roots and root channels common.
(3) 40–70 cm.	Greyish-fawn, gritty, stony loam, with occasional greenish-grey streaks and slight rusty mottling; roots cluster in greenish spots.
(4) 70–100 cm.	Fawn, gritty, stony loam, with occasional greenish-grey streaks and patches.
(5) 100–150 cm.	Shattered greenish slate with a little fine material; sides of slate fragments generally covered with dark film.
(6) 150 cm.+	Solid slate.

TABLE 6. *Analyses of Gley Podsolic Soil (over Slate), Glens of Foudland, Aberdeenshire*

Layer	(1)	(2)	(3)	(4)
Depth (in cm.)	0–15	15–25	50–60	80–90
pH	5·0	5·2	5·2	5·1
Loss on ignition %	16·4	10·6	6·2	4·0
Exchangeable Ca (m. eq.)	2·3	1·6	0·5	0·5
,, Mg ,,	1·6	0·6	0·7	0·5
,, H ,,	25·2	17·8	2·9	2·5
Clay %	17·9	24·1	22·3	11·1
Clay fraction SiO_2/R_2O_3	1·71	1·30	1·71	1·61
,, SiO_2/Fe_2O_3	10·80	4·62	7·21	6·33
,, SiO_2/Al_2O_3	2·03	1·81	2·24	2·17

Compared with the cultivated soil at Craigiebuckler, this soil shows much more definite podsolization, and there are evidences, e.g. lower pH and exchangeable calcium, that it has been less altered by cultivation and treatment.

2 (*c*) *Gley podsolic soil over Old Red Sandstone formation.*—Muir has studied three peaty gley podsols with hard-pan at Teindland. They occurred on red boulder clay and in every case an extremely hard and almost continuous iron pan was present. According to Muir the formation of this pan has led to an impedance in the drainage of the layers above it, with the result that the eluvial layer is no longer of the usual

grey tint, but tends more to an olive-grey colour. Other points noted were:

1. The clay-content of the eluvial horizon was very low and usually rose definitely on passing into the illuvial horizon.
2. A washing down of humus into the lower layers was noted in one profile.
3. Clay-fraction and ultimate analyses showed that these soils had undergone marked leaching, the leaching being as marked as in the adjoining normal podsols.
4. From the ultimate analysis of one profile it appeared that alumina had been removed only to a slight extent, especially from the lower part of the eluvial horizon. Iron, on the other hand, had been strongly leached and redeposited, mainly in the form of hard-pan; the cementing of the sand grains in the pan was due almost entirely to ferric hydroxide and other iron compounds.
5. The peaty gley podsols like the normal podsols were very acid, and the content of exchangeable bases very low, except in the A_0 horizon.
6. A slight increase in the CaO- and a sharp rise in the MgO-content was noted in the hard-pan layer, and Muir suggests this may be the reason for the precipitation of the iron.
7. In two of the profiles there were two well-defined layers above the hard-pan, and it is suggested that under the conditions associated with water-logging there is a tendency for silica to pass into the colloidal state and be leached out.

3. *Gley soils.*—Gley soils with and without a peat-covering are found throughout the area on the various geological formations. An example, without peat, is taken from near Huntly, Aberdeenshire:

Location: Leys of Drummuies.
Parent material: Boulder clay over slate.
Topography and elevation: Moderate slope; 650 ft. (198 m.).
Rainfall and drainage: About 35 in. (889 mm.); poor.
Vegetation: Pasture.

(1) 0–30 cm.	Brownish-grey loam, drying to light grey: worms and roots common.
(2) 30–50 cm.	Rusty-fawn loam; stony and fairly compact; root-channels common.
(3) 50–170 cm.	Fawn heavy loam with rusty and grey mottling in patches; stony, tough, and compact; water oozing in at 120 cm.

There is no layer of accumulation of sesquioxides, and there is evidence of gleying throughout the profile.

Peaty gley soils over Old Red Sandstone were studied by Muir at Teindland. The depth of peat found was variable, but under this the profiles were characterized by a blue-grey layer, or layers, sometimes mottled with purplish-red boulder clay. In an example from Cushley

TABLE 7. *Analyses of Gley Soil, without Peat-covering, near Huntly, Aberdeenshire*

Layer	(1)	(2)	(3)[1]	(3)[2]	(3)[3]
Depth (in cm.)	0–20	30–40	50–60	90–100	160–170
pH	5·7	5·8	5·8	5·7	6·1
Loss on ignition %	9·7	6·8	4·2	4·1	3·8
Exchangeable Ca (m. eq.)	3·3	1·9	0·9	1·9	2·0
,, Mg ,,	0·7	0·8	0·7	1·0	1·9
,, H ,,	10·1	4·6	2·9	2·5	1·0
Clay %	31·2	15·9	16·0	18·6	15·7
Clay fraction SiO_2/R_2O_3	1·54	1·55	1·47	1·92	1·85
,, SiO_2/Fe_2O_3	6·52	7·39	9·43	8·19	8·41
,, SiO_2/Al_2O_3	2·01	1·96	1·75	2·50	2·37

Moss, at Teindland, a definite increase was found in the silt and clay fractions in passing from the gleyed horizon into the unaltered till. Clay-fraction analysis showed a decided chemical leaching in the profile. There was practically no change in the SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios of the layers, but the SiO_2/Fe_2O_3 ratio fell fairly rapidly. Muir suggests that the iron removed was not deposited in the lower layers, but was washed out of the soil.

In the peaty gley soils both peat and mineral soil layers were very acid, the pH in every case being below 5 and the exchangeable bases very low.

4. *Brown soils.*—It has already been noted that certain cultivated soils in areas where the normal type is definitely podsolized have a more or less uniform brown profile, and show little or no translocation of sesquioxides. These soils may be podsolic types, modified through cultivation.

In some areas, however, the brown-soil type appears to be normal, and this type is probably associated with parent material derived from basic rocks. The area of gabbros lying round Insch, in Aberdeenshire, furnished an example of this. The rock in most places is covered with glacial drift of varying thickness, and from mineralogical examination the drift appears to resemble the underlying rock in composition.

In the profiles examined there were no morphological indications of podsolization, even under old coniferous woods. They appeared to resemble the brown earths described by certain continental workers. Gleying at various depths occurs in many of the profiles, but no subdivision of the group has been attempted at this stage.

Mitchell and Muir have recently been investigating the brown soils of the district, and have supplied the following unpublished results:

Location: Carden Wood, Logie, Pitcaple.
Parent material: Glacial drift over basic igneous rocks (gabbro).
Topography and elevation: Gentle slope; 325 ft. (98 m.).
Rainfall and drainage: About 35 in. (889 mm.); good.
Vegetation: *Pinus sylvestris* and occasional *Picea excelsa*; few mosses.

(1) 0–5 cm. Dark brown cloddy loam; occasional stones; worm- and root-channels common.

(2) 5–18 cm. Medium brown loam with slight rusty tinge towards bottom; many stones, mostly of basic igneous origin.

(3) 18–40 cm. Brown loam with slight rusty staining; occasional greyish spots; many stones; roots penetrate to 40 cm.

(4) 40–110 cm. Brown loam; rusty tinge fading out rapidly; many stones; no roots.

TABLE 8. *Analyses of Brown Soil (uncultivated) over Gabbro, Pitcaple, Aberdeenshire*

Layer	(1)	(2)	(3)	(4)[1]	(4)[2]	(4)[3]
Depth (in cm.)	0–5	5–15	15–28	40–50	60–70	100–110
pH	4·7	4·7	4·9	5·1	6·7	6·5
Loss on ignition %	40·9	24·9	10·3	5·1	4·6	4·1
Exchangeable Ca (m. eq.)	6·5	2·2	1·4	9·2	16·2	15·4
,, Mg ,,	2·1	0·6	0·1	4·3	6·8	6·0
,, H ,,	40·8	33·7	15·2	2·9	2·2	2·2
Clay %	..	19·5	12·6	15·6	20·5	18·2
Clay fraction SiO_2/R_2O_3	1·28	1·19	1·19	1·73	1·93	1·81
,, SiO_2/Fe_2O_3	5·04	5·08	4·95	6·70	5·92	5·90
,, SiO_2/Al_2O_3	1·71	1·55	1·57	2·33	2·86	2·62

Profile on cultivated ground

Location: Cultivated ground adjacent to previous profile.
Parent material: Glacial drift over basic igneous rocks (gabbro).
Topography and elevation: Gentle slope; 325 ft. (98 m.).
Rainfall and drainage: About 35 in. (889 mm.); good.
Vegetation: 15-year-old grass.

(1) 0–25 cm. Medium brown heavy loam; crumbly structure; many roots and stones; worms common.

(2) 25–50 cm. Yellowish-brown medium loam; many stones and roots; no worms observed.

(3) 50–100 cm. Light brown with slight greyish and rusty spotting in places; very compact; roots few and small; many stones.

(4) 100–140 cm. Brown rotten rock; sandy and loose in texture.

It will be observed from the analyses of these two profiles that they bear no relation to the podsolized types already described. There is no translocation of sesquioxides and no morphological evidence of podsolization. It appears to be characteristic of these soils to have a marked rise in pH and exchangeable cations at a depth of about 70 cm. They appear to have much in common with the brown earths described by certain continental workers, but it will be noted that the pH at the surface is low, and that there is considerable leaching of bases from the surface-layers. Similar soils have been described by Robinson in Wales.[1]

[1] *Empire J. Expt. Agric.*, 1934, **2**, 258.

TABLE 9. *Analyses of Brown Soil (cultivated) over Gabbro, Pitcaple, Aberdeenshire*

Layer	(1)	(2)	(3)[1]	(3)[2]	(3)[3]	(4)
Depth (in cm.)	0–25	25–35	50–60	70–85	90–100	130–140
pH	5·1	5·6	5·7	5·7	5·6	5·8
Loss on ignition %	14·9	8·6	4·4	4·8	4·1	2·7
Exchangeable Ca (m. eq.)	6·6	3·4	4·3	14·1	10·4	10·8
,, Mg ,,	0·5	0·3	0·4	4·7	2·7	2·4
,, H ,,	11·9	8·4	2·3	2·6	1·8	1·3
Clay %	20·9	11·2	12·9	14·3	4·8	4·1
Clay fraction SiO_2/R_2O_3	1·19	1·11	1·48	1·74	1·57	1·64
,, SiO_2/Fe_2O_3	4·44	4·64	6·28	6·28	5·97	6·16
,, SiO_2/Al_2O_3	1·63	1·46	1·93	2·41	2·13	2·23

Lysimeter studies.—Under the direction of Hendrick, three lysimeters were erected at Craibstone, near Aberdeen, and by means of these, soil drainage has been studied[1] for the past seventeen years on a soil derived from glacial drift consisting mainly of granites and granitic gneisses. (See p. 251 and Table 2 for description and analyses of soil adjoining the lysimeters.)

The lysimeters were constructed without disturbing the enclosed blocks of soil, and the soil has been cropped according to the usual rotation followed in the district. The most important results are as follows:

1. In the cool, moist climate of Aberdeen more than half the precipitation passes through the soil as drainage.
2. The nitrogen removed from the soil in the drainage water is much less than was expected, and is almost entirely in the form of nitrate. The average amount over a period of eleven years was about 12 lb. per acre per annum, and the amount washed out from the manured lysimeters was no greater than from the unmanured. The amount of nitrogen removed in crops is immensely greater than that removed by drainage.
3. No appreciable amount of phosphoric acid has ever been found in solution in the drainage water of any of the lysimeters.
4. Potash is washed out in similar amount to nitrogen, viz. about 12 lb. per acre per annum, and as in the case of nitrogen, no more is removed from the manured than from the unmanured lysimeter.
5. In addition to potash, large amounts of lime and soda and considerable quantities of magnesia are washed away in solution in the drainage water. In many cases more soda is removed than lime.
6. Carbonates are practically absent in the drainage, but it contains considerable amounts of silicic acid.

Soil fertility estimations.—Most of the soils in the north-eastern region are decidedly acid in reaction, and the pH of the cultivated soils is generally in the neighbourhood of 5·5. The principal crops grown, however, are well suited to soils of moderate acidity, and many of the soils

[1] *Trans. Highland and Agric. Soc. Scotland*, 1921, **33**, 56; 1930, **42**, 1; 1932, **44**, 86; 1934, **46**, 202.

have reserves of lime and potash in the form of silicates, which appear in many cases to obviate the necessity for frequent liming. The results of an investigation carried out a few years ago on 'Certain Acid Soils and Growth of Sugar Beet' have been given by Newlands.[1]

Recently, at the Macaulay Institute, Stewart and Robertson have carried out Mitscherlich tests, field and pot, on a series of soils in the north-east. They have found that the contents of available potash in an average soil amounted to slightly less than 1 cwt. per acre K_2O and the available phosphate to about 1 cwt. per acre P_2O_5, i.e. according to Mitscherlich's relative-yield curves the soils show rather greater deficiencies in phosphoric acid than they do in potash. In addition, Stewart has carried out numerous tests in connexion with advisory work for farmers. The methods normally used in this work are as follows: readily soluble potash is estimated in an 0·5 N acetic-acid extract, and phosphoric acid either in this extract by Prescott's volumetric molybdate method, or colorimetrically in an 0·2 N hydrochloric-acid extract according to a modification of Kirsanov's method.

His results show that in general the lime required to bring the soils to a pH of 6·3 may be anything up to about 3 tons per acre calcium oxide. The figures for phosphoric acid generally range from 2 to 10 mg. P_2O_5 per 100 gm. soil, and common values for the potash-content are from 4–8 mg. K_2O per 100 gm. soil. These tests have been correlated with the Mitscherlich pot- and field-experiments, and the general conclusion reached is that the majority of the soils are deficient in phosphoric acid, and a smaller number are deficient in potash.

[1] *J. Agric. Sci.*, 1928, **18**, 704–12.

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SOME ASPECTS OF THE BLACK COTTON SOILS OF CENTRAL PROVINCES, INDIA

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With Plate 18

BLACK soils are very commonly met with throughout the Central Provinces on different geological formations, such as (1) Deccan trap or basalt, (2) sandstone belonging to the Vindhyan system, and (3) the gneissic rocks. These black soils vary considerably in depth and clay-content, according to their position. Those situated at lower levels are generally deep and heavy and contain about 40 to 50 per cent. of clay. The lime-content of these soils generally varies inversely with the rainfall of the localities in which they are found; for instance, black soils of the western part of the Central Provinces usually contain more calcium carbonate than those of the eastern districts, in which the percentage of calcium carbonate is often as low as 0·01. There are, however, special cases in which certain fields that have been subjected to very heavy leaching show an insufficiency of calcium carbonate, whereas others in the same locality contain a reasonable proportion of it. The type of crops grown on the various black soils of the Central Provinces depends, therefore, on the physical characteristics of the soils and the rainfall. Some typical figures of mechanical and chemical analyses of various types of black soils of these Provinces are given in Table 1, which will substantiate the above-mentioned general observations regarding these soils.

Black Cotton Soils

Soils derived from the weathering of trap rock, in particular, which are black, heavy, and climatologically suited to the growth of cotton, are known as black cotton or *regur* soils. They are very common in the trap area, but occasionally a black-cotton-soil formation occurs on a gneissic rock. These soils may have a depth of 2–3 ft. to even 30–40 ft. Ordinarily the depth of black soils utilized for the growth of cotton does not exceed 10 to 15 ft. The deeper soils are put under wheat and other winter crops. The kind of crops grown on this class of soil depends, apart from its depth, to a large extent on the total amount and distribution of the rainfall. It is thus a very common practice to grow cotton on black soil of 10 to 20 ft. depth in districts with a low annual rainfall, i.e. 15 to 20 in., whereas a similar soil would be put under wheat, gram, or peas in districts with a high rainfall, i.e. 35 to 45 in. The soil does not as a rule show any marked horizons in its profile. Samples of black cotton soil, throughout its profile, were taken from the Agricultural College Farm, Nagpur, and subjected to mechanical and chemical analyses; the results obtained are given in Table 2. A photograph of the profile (Plate 18) shows that there is very little difference between the soil and the subsoil. Owing to the washing down of clay particles from the surface-soil, the subsoil is very sticky, and when cut shows a very shiny

TABLE I. *Mechanical and Chemical Composition of Black Soils from the Central Province and Berar (samples taken to a depth of 8 inches)*

Locality from which samples were taken	*Normal annual rainfall** *(inches)*	*Crops normally grown*	*Kind of underlying rock*	*Percentages in air-dry soil passed through one or two M.M. sieve*										
				Moisture	*Loss on ignition*	$CaCO_3$	*Coarse sand*	*Fine sand*	*Silt*	*Fine silt*	*Clay*	*Loss by solution in peroxide, HCl treatment*	*Nitrogen*	*pH*
				†Figures as obtained by the sedimentation method										
Akola district	30·3 in.	Cotton Juar (*sorghum vulgare*)	Deccan trap (Basalt)	7·35	7·00	6·32	2·62	8·53	15·84	19·09	36·92	..	0·038	8·0
,,		,,	,,	9·98	7·47	3·21	0·40	5·46	12·80	18·26	44·35	..	0·033	8·1
Wardha district	41·6 in.	,,	,,	6·64	6·02	4·10	2·38	5·99	13·13	20·03	41·51	..	0·050	8·0
,,		Cotton or wheat	,,	9·80	7·10	0·80	0·10	3·61	11·68	16·04	51·45	..	0·048	8·0
,,		Wheat	,,	11·04	6·43	0·35	0·20	3·03	12·42	15·58	51·00	..	..	8·0
Nagpur district	46·6 in.	Cotton Juar	,,	5·31	4·43	0·97	12·40	7·02	14·44	14·60	41·18	..	0·047	7·70
				Figures as obtained by the revised British official method										
Drug district	48·2 in.	Rice	Rocks belonging to the Cuddapah and Vindhyan systems, mainly composed of much indurated and compacted shales, slates, quartzites, limestones and sand-stones	3·03	..	0·12	10·71	20·31	29·35	..	37·40	0·87	..	6·5 to 6·8
,,		Wheat	,,	6·21	..	0·01	4·65	18·44	27·45	..	43·45	0·67	..	,,

* Figures as given by the Indian meteorological department.

† This does not apply to the last three columns.

TABLE 2. *Mechanical and Chemical Composition of a Profile of Black Cotton Soil from the Central Provinces and Berar*

Kind of soil	Locality	Normal annual rainfall (inches)	Crops normally grown	Kind of under-lying rock	* Percentages in air-dry soil														
					Mois-ture	Loss on ignition	$CaCO_3$	Coarse sand	Fine sand	Silt	Fine silt	Clay	Loss by solution in per-oxide, HCl treat-ment	Total P_2O_5	Total K_2O	Available P_2O_5	Available K_2O	Nitro-gen
(1) Black cotton, surface-soil to a depth of 8 inches	Nagpur district	46·6	Cotton Juar	Deccan trap (Basalt)	6·08	10·62	0·68	2·41	6·23	12·00	15·30	44·85	2·79	0·079	0·262	0·005	0·006	0·049
(2) Black cotton, subsoil, between 2 ft. and 4 ft. (from 1 above)	,,	,,	. .	,,	7·52	11·12	0·80	1·21	4·13	12·15	13·50	49·85	2·55	0·062	0·286	0·003	0·002	0·041
(3) Black cotton, soil, below 4 ft (from 1 above)	,,	,,	. .	,,	5·73	9·79	14·40	0·93	4·78	12·45	17·15	36·55	2·81	0·076	0·172	0·002	0·010	0·029

* Figures according to the official method adopted by A.E.A. England, 1925.

surface. Figures of analyses of the subsoil sample also show a higher percentage of clay than that found in the surface-soil. The layer of the semi-weathered rock—which is greyish-white in this particular instance—begins at a depth of about 4 to 4½ ft. from the surface. The lime concretionary bed also begins at about the same depth. Occurrence of such lime concretions is a common feature of black cotton soils, but their exact position in the soil profile depends on the depth of the soil. The downward movement of calcium in black cotton soils can be clearly seen from its increasing percentages from the surface to the lower depths. The extent to which silica is leached from the surface-soil is seen from the figures of fusion analysis of the clay-fractions obtained from the various depths of the soil profile. Clay-fractions used for the purpose of this analysis were obtained according to the method described by Robinson [1]. Results obtained are given in Table 3.

TABLE 3. *Results of Fusion Analyses of Clay-Fractions from Black Cotton Soil*

Depth at which sample was taken	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3 (*molecular*)	SiO_2/R_2O_3 (*molecular*)
9 in.	57·76	26·26	15·81	3·73	2·69
Below 2 ft.	60·40	26·42	16·98	3·88	2·75
Below 4 ft.	61·40	22·64	16·74	4·60	3·13

Black cotton soils of this Province, as well as those found in other parts of India, generally contain a very low percentage of organic matter. This is due to the soils being subjected to a high temperature throughout the year; during the hot weather the maximum temperature of the soil in many instances rises as high as 120°–130° F. The average annual rainfall is not more than 40 in. and in many places it is only 15 to 20 in., almost all of it falling within 3 to 4 months. These arid climatic conditions (as opposed to those of the chernozem belt) are particularly conducive to the rapid oxidation of organic matter, and, in the absence of any very marked additions of organic matter in the form of organic manures or crop residues from year to year, the soils have become deficient in humic material.

Biological Aspects of Black Cotton Soil

Much interest is being shown in the black soils of India because they resemble in certain respects the chernozems that have been intensively studied by workers on the Continent. The biological aspects of black cotton soil have been investigated by the writer for some time, but the information obtained has not yet been published in full. This information has therefore been put together and is presented here briefly.

Rate of decomposition of organic matter.—The rate of decomposition of carbon in black cotton soil was studied on two different types of green manures [2]. Determinations of carbon dioxide were made daily until the amount produced decreased considerably below that given off on the first day. Results obtained are given in Table 4.

The figures given below clearly indicate that the rate of biological oxidation of organic matter in these soils is very vigorous, and, as mentioned before, that accumulation of organic matter cannot be very striking under the conditions obtaining in these soils.

TABLE 4. *Total Amount of Carbon Dioxide evolved and Percentage of Carbon oxidized from Green Manures in* 16 *days*

Kind of green manure	*Total carbon added as green manure, in mg. per* 100 *gm. of soil*	*Total carbon dioxide evolved, in mg. per* 100 *gm. of soil in* 6 *days*		*Total carbon oxidized in* 6 *days* %
		As CO_2	As C	
Sann hemp (*Crotalaria Juncea*)	313·60	367·62	100·2	31·96
Dhaincha (*Sesbania aculeata*) .	318·00	350·90	95·70	30·10

Relation of moisture-content of the soils to biological activity.—The maximum water-holding capacity of the black cotton soils, as determined by Hilgard's method, varies from 60 to 70 per cent., depending upon their clay-content. Experience with light soils shows that the biological activities of these soils are at their best when the moisture-content is about three-eighths of the maximum water-holding capacity. In heavy black cotton soil, however, the biological activities are at their best when the moisture-content is about one-half the maximum water-holding capacity, showing that with heavier soils a higher moisture saturation is necessary for the normal functioning of the beneficial soil organisms. This fact is very clearly seen from Fig. 1, which shows the rate of nitrifying-capacity of fresh samples of black cotton soil, taken at periodic intervals, and containing varying percentages of moisture [3].

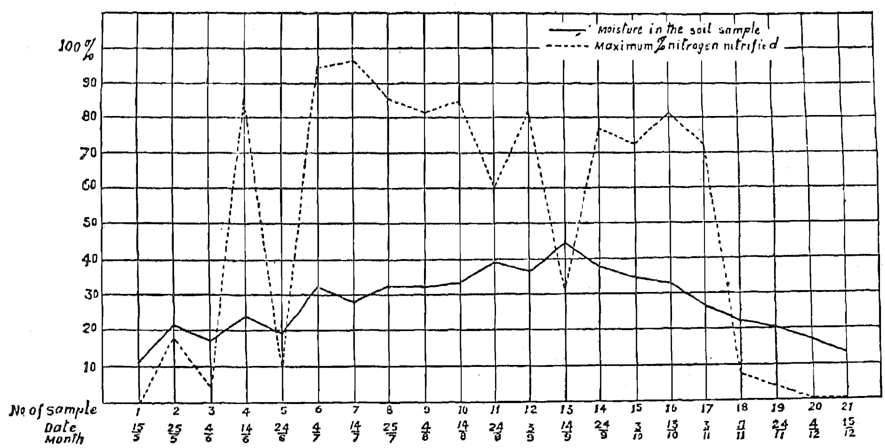

FIG. 1. Variations in the moisture-content of the black cotton soil at different periods and maximum percentage of added nitrogen nitrified in eight weeks. (Maximum water-holding capacity of the soil was 60 per cent.)

Results of nitrification tests with varying percentages of moisture, obtained with air-dry soil samples artificially watered, agree in general very closely with those obtained with soil samples taken direct from the field and shown in Fig. 1. The chief point of difference between the nitrifying capacity of artificially watered air-dry soils and that of moist soils collected from the field was that in the former nitrification appeared to be slow in starting. The total amount of organic nitrogen nitrified at the end of 8 weeks by both types of soils is approximately the same, but soils which have been receiving rain for some time can start their nitrifying action much quicker than air-dry soil brought at once to a 30 per cent. moisture-content. From the observations recorded in Fig. 1, it is further seen that, under natural conditions of climate and rainfall, black cotton soil shows considerable biochemical activity only during four months of the year. A study of the rate of oxidation of organic matter, as measured by the evolution of carbon dioxide, in soil containing varying percentages of moisture, also corroborated the finding mentioned above. Under favourable conditions of moisture the soil can nitrify, very efficiently, organic and mineral nitrogen from various sources. Experiments [4] carried out to study this particular aspect showed that 65–85 per cent. of nitrogen from various types of oil-cakes and green manures added to the soil was nitrified in 8 weeks, and 90 to 95 per cent. of nitrogen added to the soil in the form of ammonium salts or free ammonia was nitrified in a period of 4 weeks only.

The physical condition of the soil also profoundly affects the rate of nitrification. Black cotton soil when moistened with water by hand, for example, assumed a lumpy form very different in texture from that of a soil containing the same amount of water in the field. To determine the effect of the texture of the soil upon its nitrifying power an experiment was carried out in which 30 per cent. of water was allowed to diffuse into the soil without mixing by hand. The results obtained are shown in Table 5.

TABLE 5. *Nitrification of Oil-cake in Black Cotton Soil containing 30 per cent. moisture*

Kind of treatment	*Percentages of added nitrogen nitrified**			
	After 2 weeks	*After 4 weeks*	*After 6 weeks*	*After 8 weeks*
Soil moistened with water by hand	1·90	43·40	78·85	89·60
Soil moistened by allowing the water to diffuse	18·40	62·90	85·40	93·90

* Nitrified nitrogen includes both nitrite and nitrate nitrogen.

The above details of the nitrifying capacity of black cotton soils indicate that the power of this soil to form ammonia from organic nitrogen from various sources must also be vigorous, and actual experiments carried out to test this particular point have fully substantiated the expectation. In order also to ascertain the individual efficiency of the ammonifying organisms of black cotton soil, nine individual strains of bacteria commonly developing on ordinary agar plates were isolated and purified, but

no attempt was made to identify any of them. These individual strains of bacteria were inoculated into 100 c.c. of Remy's peptone solution, incubated for seven days, and the amount of ammonia formed was determined. It was found that eight out of the nine strains isolated were quite efficient ammonifiers. It was further found that the nitrifying organisms of the soil can tolerate a fairly high concentration of free ammonia and form nitrates from it in the soil [5]. The rate of nitrification with varying concentrations of free ammonia in the soil is given in Table 6.

TABLE 6. *Nitrification of Ammonia in Varying Concentrations*

Milligrams of nitrogen as ammonia, added per 100 grams of soil	*Percentages of added nitrogen nitrified*			
	After 2 weeks	*After 4 weeks*	*After 6 weeks*	*After 8 weeks*
10	80·10	83·00	102·00	102·00
20	70·05	76·75	96·00	96·00
30	74·00	90·00	98·00	98·00
60	34·00	94·00	94·00	92·00
80	5·40	70·00	94·50	94·50
100	3·90	55·10	88·20	92·20
200	Nil	Nil	Nil	6·40
250	Nil	Nil	Nil	0·60

An examination of the figures given above shows that a concentration of ammonia up to 60 mg. nitrogen per 100 gm. of soil, does not materially affect the usual course of nitrification. When the concentration is raised to about 80 or 100 mg. of nitrogen per 100 gm. of soil the nitrifying organisms are affected in the beginning, but they recover from the adverse effects within about a month. Concentrations of over 100 mg. of ammoniacal nitrogen per 100 gm. of soil are very injurious to nitrification. It may, however, be mentioned that under ordinary conditions of manuring and cultivation there is never any possibility of the occurrence in the soil of such high concentrations of ammonia as those employed in the experiment mentioned above.

Summary

1. A brief account is given of the chemical and biochemical aspects of black cotton soil.

2. The lime-content of these soils generally varies inversely with the rainfall of the localities in which they are found.

3. Appreciable amounts of calcium and silica are leached from the surface-soil.

4. A certain amount of clay is also washed down continually from the surface-soil.

5. These soils contain a low percentage of nitrogen and organic matter.

6. The rate of (*a*) biological oxidation of organic matter, and (*b*) formation of ammonia and nitrates from organic nitrogen, in these soils is very vigorous.

7. In these heavy soils the biological activities are at their best when the moisture-content is about half the maximum water-holding capacity.

8. Nitrification in artificially watered soils previously air-dried is slower in starting than with soils receiving natural rainfall, but the nitrifying efficiency after a period of 8 weeks is about the same.

9. A heavy clay soil that has lost its texture shows at first a diminished nitrifying power when compared with the same type of soil in good condition.

10. The nitrifying organisms of the soil can tolerate a fairly high concentration of free ammonia, and form nitrates from it in the soil.

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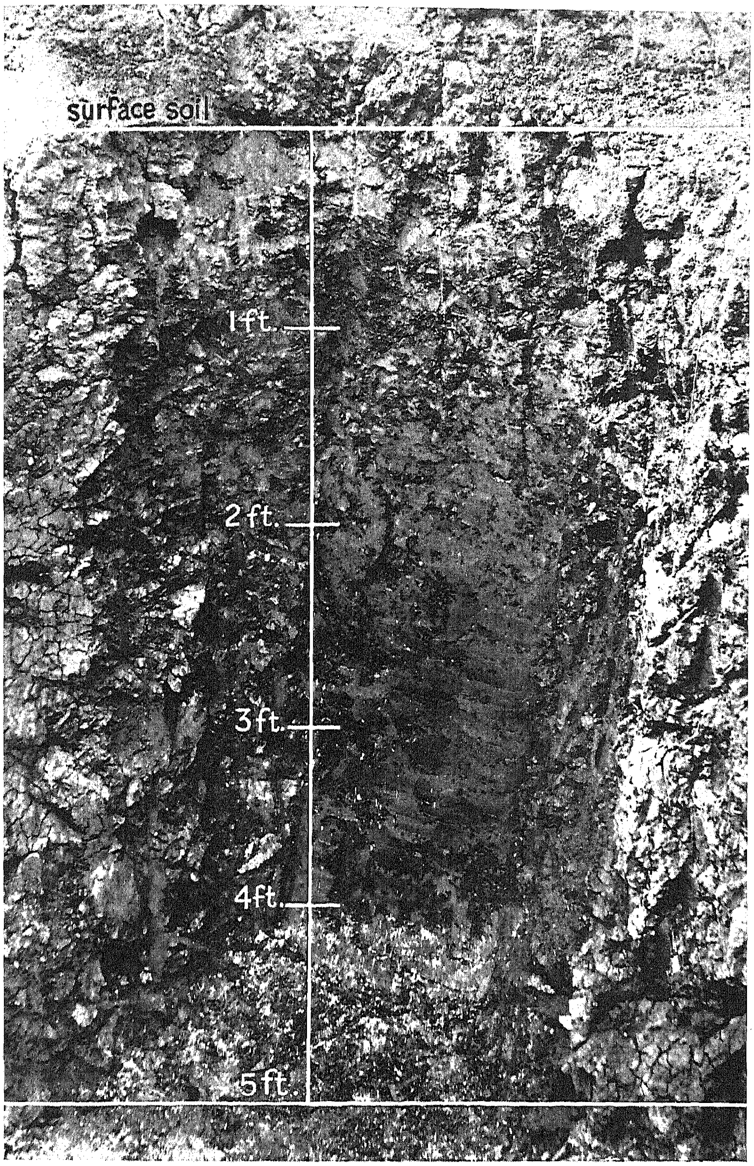

A profile of black cotton soil from the Agricultural College Farm, Nagpur, India

SOILS OF YORKSHIRE

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Natural Features.—By far the largest county in Great Britain, Yorkshire covers an area of about 3,871,000 acres, of which 65·4 per cent. is under crops and grass. In its physical aspect it is constituted of four hilly regions, with large tracts of flat land between them. The Pennine Range, 'the backbone of England', occupies a large area of the county and forms the western boundary. The Yorkshire Pennines are divided into two parts by the Aire Gap; the northern part is mountainous with several peaks above 2,000 ft., the highest being Mickle Fell (2,591 ft.). Nevertheless, this area provides in parts some excellent sheep-grazing of the fescue type, and is sprinkled with very picturesque dales, in which occur alluvial stretches of high fertility. The southern half of the Pennines includes the greater part of the industrial West Riding, one of the most densely populated areas in the country. The higher land (1,000–1,500 ft.) consists of uncultivated grouse moor, covered with heather, *nardus* and *eriophorum*.

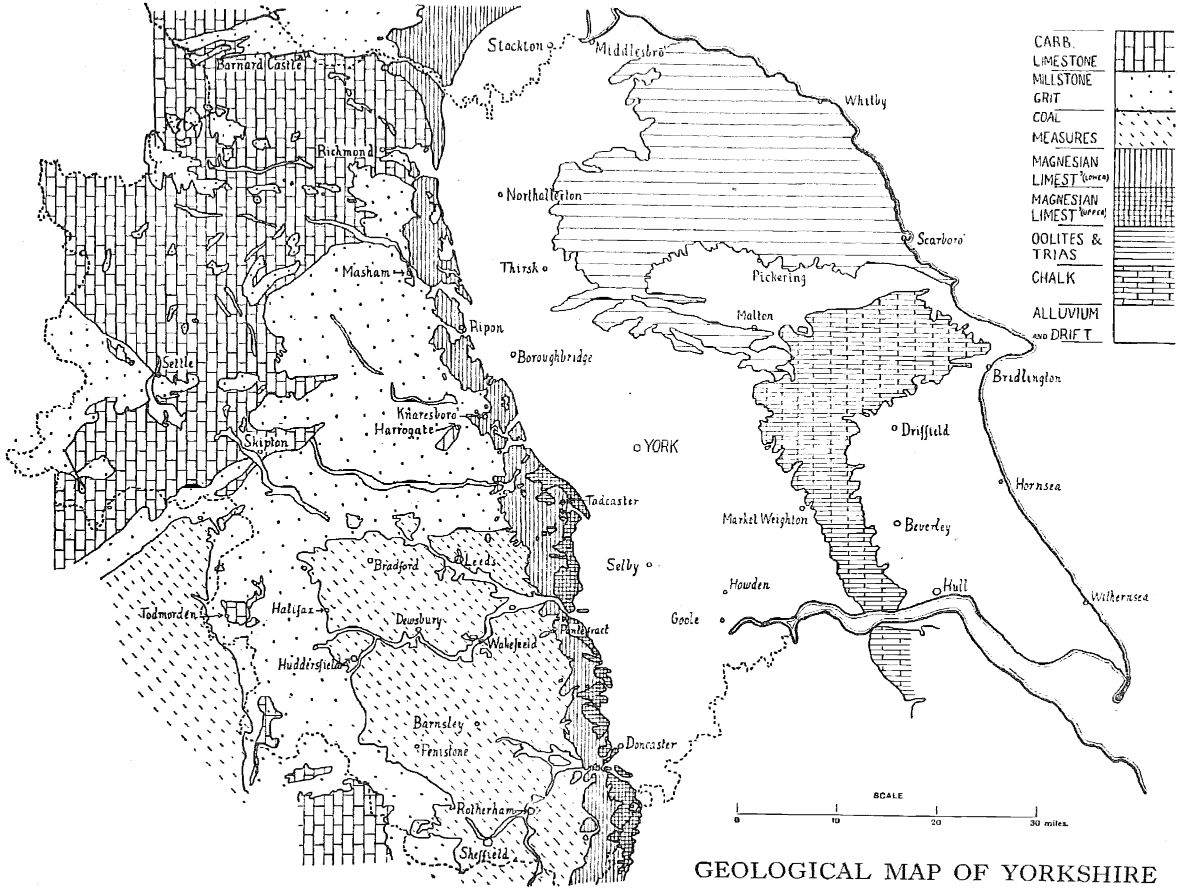
The Cleveland and Howardian hills occupy about 1,000 square miles in the north-eastern part of the county; they are very thinly populated and consist mainly of uncultivated moorland, at altitudes well over 1,000 ft. above sea-level. The Wolds, forming the fourth hilly region, are separated from the Clevelands by the Vale of Pickering, and stretch in a wide band from the North Sea to the Humber, the southern boundary of the county.

From the Pennines on the west and the other hills on the east several rivers converge on to the extensive central plain of the county, known as the Vale of York, and all finally reach the sea at the Humber estuary.

Climate.—The highest mean annual rainfall occurs on the Pennines, where in places it exceeds 60 in., though for altitudes of 800–1,000 ft. it amounts only to 40 or 45 in. At altitudes below 150 ft. it is of the order of 25 in., distributed fairly evenly over the year. The eastern part of the county is drier than the west, but the mean temperature is fairly constant, as is shown by the following data:

Station	Altitude (*ft.*)	Mean annual rainfall (*in.*)	Mean monthly temperature °F.	
			max.	*min.*
Meltham (West)	514	44·6	53·6	40·2
York	57	24·2	55·2	41·4
Scarborough	158	25·8	53·6	42·5
Hull (East)	18	25·4	53·9	41·9
Harrogate	478	30·6	52·6	40·8

Geology.—The oldest rocks in Yorkshire are the Ingletonian beds, of the Ordovician System, covering a small area in the north-west corner of the county. Rocks of the carboniferous series form the remainder



GEOLOGICAL MAP OF YORKSHIRE

of the western half of the county, limestone in the north, millstone grit in the middle, and coal measures in the south.

Running north and south through the middle of the county there occurs a narrow belt of Permian rocks resting successively on carboniferous limestone, millstone grit, and coal measures. The magnesian limestone of this belt is a rich source of agricultural lime. Lime is also produced from the oolitic limestone which forms the southern boundary of the Jurassic rocks of the Cleveland and Howardian Hills. Jurassic rocks also underlie the chalk in the Wolds of the East Riding.

Throughout Yorkshire there is evidence of glacial action, and the deposits of drift-material attain depths of over 100 ft. in parts of the Vale of York. This drift, in addition to local material, contains stones originating in Scottish and Cumberland rocks. Small outcrops of Trias and Lias appear in this plain. The boulder clay of the Holderness and of the eastern fringes of the Wolds was deposited by the North Sea glacier. The Vale of Pickering in many respects resembles the southern portion of the Vale of York; it is levelled with ancient and modern alluvium, partially covering the boulder clay, and there is evidence that this vale was at one time an inland lake.

Other recent deposits include wind-blown sands, especially in the Vale of York, and there are extensive areas of artificially deposited warp along the banks of the Derwent, Ouse, and Humber.

Soil Types

No systematic survey of Yorkshire soils has as yet been started, but the information available from the intensive study of isolated areas leads to the conclusion that the predominating influence in the formation of soil types in Yorkshire, as in other parts of the country, is the underlying rock or parent material. It is true that in some areas, such as the deciduous forest of Knaresborough, the combined influence of climate and vegetation has obliterated the effect of the parent material to such an extent that some soils derived from millstone grit are almost indistinguishable from some magnesian limestone soils.

Podsols.

In the millstone grits podsol-formation is quite common at altitudes above 700 or 800 ft. Below this level the land is generally cultivated, and in parts is covered with boulder clay, so that any podsols which may have been formed are obscured. Coal-measures sandstone, though much finer in grain than millstone grit, is similar to it in mineralogical composition, but podsols are rare in the coal-measures area, deep layers of peat occurring at the higher altitudes.

Lowland podsols also are found in the eastern half of the Vale of York, iron-pan formation being a feature of some of the 'commons'. Humus podsols are rarer, but a good example is seen in Strensall common. The depth of drift material here is about 60 ft. and consists of a 6-ft. layer of sand overlying stiff boulder clay. Altitude—60 ft., rainfall—25 in.

The description of the sand profile is as follows:

0–6 in.	Peaty sand.
6–14 ,,	Bleached sand.
14–18 ,,	Black-humus layer.
18–48 ,,	Yellow sand.
48–72 ,,	Reddish sand.

The following are the analytical data:

	0–6 in.	*6–14 in.*	*14–18 in.*	*18–48 in.*	*48–72 in.*
Mechanical Analysis:[1]					
Coarse sand (per cent.)	19·25	25·45	15·30	26·63	29·67
Fine sand (per cent.)	68·70	71·40	71·50	68·46	66·25
Silt (per cent.)	1·30	0·36	0·78	2·10	1·88
Clay (per cent.)	2·70	1·62	4·97	1·10	0·88
Moisture (per cent.)	1·08	0·20	1·59	0·36	0·31
Loss on ignition (per cent.)	9·61	1·42	8·82	1·55	0·90
Other data:					
Fe_2O_3 (sol. in HCl) (per cent.)	0·09	0·17	0·42	0·56	0·94
Al_2O_3 (sol. in HCl) (per cent.)	0·71	0·77	0·61	0·80	0·71
Organic carbon (per cent.)	4·63	0·72	4·25	0·12	0·19
Nitrogen (per cent.)	0·18	0·022	0·17	0·014	0·015
C/N	26·31	32·8	25·01	8·25	12·54
pH	3·36	3·83	3·51	4·34	4·29

The vegetation of this area, once under deciduous forest, consists mainly of heather (*calluna*) and bracken (*pteris*). Each of the four upper horizons, A_0, A_1, B, and C, is clearly marked. There is clear evidence of humus-accumulation in the B horizon; accumulation of the finer mineral particles also is suggested, but sesquioxides appear to be fairly uniformly distributed throughout the profile.

A different type of podsol occurs at Cropton Moor on land belonging to H.M. Forestry Commission. It lies at an altitude of 600 ft. above sea-level and the average rainfall is about 45 in. The parent material consists of a thin sandy drift-layer overlying stiff Oxford clay, the natural vegetation consisting chiefly of heather. A thin iron pan, rich in humus and formed from the upper drift, lies on the surface of the clay, which is extremely acid in reaction.

The layers in the profile are:

0–4 in.	Peat.
4–8 ,,	Greyish sand.
8–10 ,,	Reddish-black, indurated layer.
10–16 ,,	Mottled clay.
16 in. +	Greenish-brown clay.

[1] The mechanical analyses in this investigation were carried out according to the 1928 International Methods; Organic Carbon and Nitrogen, by the method described by Robinson, McLean & Williams (*J. Agric. Sci.*, 1929, **19**, 315).

	0–4 in.	4–8 in.	8–10 in.	10–16 in.	16 in.+
Mechanical analysis:					
Coarse sand (per cent.)	..	18·90	16·99	2·92	0·53
Fine sand (per cent.)	..	65·30	59·70	22·73	21·01
Silt (per cent.)	..	6·00	8·85	24·45	32·95
Clay (per cent.)	..	8·20	7·90	42·72	39·05
Moisture (per cent.)	3·68	0·45	1·15	2·62	2·77
Loss on ignition (per cent.)	33·77	4·16	6·15	5·71	5·76
Other data:					
Fe_2O_3 (sol. in HCl) (per cent.)	0·24	0·07	1·56	4·34	4·54
Al_2O_3 (sol. in HCl) (per cent.)	0·38	0·53	1·75	5·90	5·71
Organic carbon (per cent.)	20·82	2·53	2·44	0·60	0·52
Nitrogen (per cent.)	0·86	0·14	0·12	0·11	0·10
C/N	24·27	18·36	19·86	5·68	5·20
pH	3·81	4·08	4·14	4·15	4·15

Post-Glacial Soils.

The Vale of Pickering resembles the Vale of York in the variety of the soil types that are found therein. Alluvium, lacustrine clay, sands, and peat have been superimposed on the boulder clay previously deposited; this clay is, however, exposed in some small areas and forms the soil of the higher lying ground at altitudes between 100 and 130 ft., the general level of the plain being about 80 ft. above sea-level.

Most of the alluvial soils suffer from impeded drainage, and consist of material rich in clay, which in parts is suitable for brick-making. In general this land is under permanent pasture. A typical profile occurs near Kirkby Misperton.

0–12 in. . . . . Dark brown loam.
12–24 ,, ... Brown clay.
24–36 ,, ... Light brown sandy clay.
36–60 ,, ... Blue clay.

	0–12 in.	12–24 in.	24–36 in.	36–60 in.
Mechanical analysis:				
Coarse sand (per cent.)	6·01	3·85	23·24	2·10
Fine sand (per cent.)	27·26	33·46	39·36	4·00
Silt (per cent.)	16·57	23·30	12·23	26·84
Clay (per cent.)	38·25	36·05	21·02	57·68
Moisture (per cent.)	3·25	2·45	1·45	3·15
Loss on ignition (per cent.)	13·26	5·21	3·31	9·70
Other data:				
Organic carbon (per cent.)	6·79	0·67	0·46	1·29
Nitrogen (per cent.)	0·36	0·054	0·059	0·073
C/N	18·81	12·46	7·91	17·63
pH	6·51	6·84	7·34	7·57

The major differences between these various horizons have probably existed since deposition, but the pH figures imply that podsolization may be proceeding.

In all parts of the plain there are large areas of soil known as 'carr'. This consists of a profile normally of two horizons, a peaty soil overlying clay. The water-table is invariably high and often coincides with the junction between the two horizons. The clay horizon is usually alkaline and the peat horizon is only slightly acid. Along the southern boundary of the lake the clay horizon is almost non-existent and is replaced by chalk debris. Such a profile as this occurs at East Heslerton, the description and analytical data being as follows:

0–6 in.	Brown peaty loam.
6–12 ,,	Black peaty loam.
12–14 ,,	Greyish sand.
14 in.+	Chalky sand.

	0–6 in.	*6–12 in.*	*12–14 in.*	*14 in.+*
Mechanical Analysis:				
Coarse sand (per cent.)	17·48	22·60	62·38	54·67
Fine sand (per cent.)	4·79	23·11	22·31	28·44
Silt (per cent.)	12·36	8·28	7·47	9·20
Clay (per cent.)	13·85	15·67	4·70	4·50
Moisture (per cent.)	5·26	4·10	0·73	0·56
Loss on ignition (per cent.)	47·96	26·36	3·51	3·27
Other data:				
Organic carbon (per cent.)	25·63	12·54	2·42	0·79
Nitrogen (per cent.)	1·91	1·25	0·14	0·05
C/N	13·44	10·06	17·86	15·01
pH	6·49	5·68	6·18	7·5

Post-glacial sand forms the soil along the edge of the Pickering 'lake'. This band of sand is approximately 500 yards wide, and along the southern edge overlies flinty chalk drift. Such a profile, seen at East Heslerton, shows the following characteristics:

0–9 in.	Greyish brown sand.
9–18 ,,	Brown sand.
18–22 ,,	Dark coloured sand.
22–28 ,,	Brown flinty sand.
28 in.+	White flinty layer.

	0–9 in.	*9–18 in.*	*18–22 in.*	*22–8 in.*	*28 in.+*
Mechanical analysis:					
Coarse sand (per cent.)	59·75	58·82	50·01	53·95	53·62
Fine sand (per cent.)	22·26	27·37	33·95	30·36	30·08
Silt (per cent.)	3·78	1·13	4·06	5·83	10·30
Clay (per cent.)	6·20	4·97	4·72	5·92	3·20
Moisture (per cent.)	1·15	1·08	1·06	0·80	0·37
Loss on ignition (per cent.)	5·08	3·78	3·56	3·48	3·96
Other data:					
Organic carbon (per cent.)	2·57	1·30	0·87	0·80	0·51
Nitrogen (per cent.)	0·33	0·13	0·16	0·07	0·05
C/N	7·84	10·00	5·58	11·00	9·50
pH	7·24	7·35	7·50	7·50	7·50

Most of the soil types occurring in the Pickering district are repeated in the southern half of the Vale of York, which, however, contains some types not found in the former area. The diversity of the soil types in the area south of York is extremely baffling to the cultivator; it is not uncommon to come across the sand type, 'carr', and clay all within the confines of one small field. A particularly interesting clay profile occurs near Wheldrake. It consists of a comparatively thin layer of calcareous boulder clay overlying a layer of sand and gravel, the latter being waterlogged almost throughout the year. This area is situated about 30 miles from the sea, but the altitude is less than 40 ft.

The description of the profile is as follows:

0–8 in.	Dark brown loam.
8–18 ,, ...	Brown clay.
18 in.+	Light brown sand.

	0–8 in.	*8–18 in.*	*18 in.+*
Mechanical Analysis:			
Coarse sand (per cent.) . .	3·91	0·95	20·48
Fine sand (per cent.) . .	28·01	2·57	64·07
Silt (per cent.) . . .	36·34	24·88	5·27
Clay (per cent.) . . .	21·58	57·92	8·28
Moisture (per cent.) . .	2·75	3·76	2·66
Loss on ignition (per cent.) .	9·00	9·97	3·47
Other data:			
Organic carbon (per cent.) .	6·64	0·72	0·25
Nitrogen (per cent.) . .	0·57	0·03	0·02
C/N	11·73	28·9	12·48
pH	7·38	7·22	7·44

Such areas as this, although numerous, are comparatively small in extent, and are normally under permanent grass.

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FURTHER EXPERIMENTS ON THE INTERRELATION OF FACTORS CONTROLLING THE PRODUCTION OF COTTON UNDER IRRIGATION IN THE SUDAN

Pt. I. EXPERIMENTAL

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Introduction.—In a paper [1] published in 1932 the results were given of an experiment, made in 1929–30, comparing the four factors of sowing-date, spacing, amount of irrigation, and nitrogenous manuring, in all combinations, on cotton grown under the Gezira Irrigation Scheme. The experiment was repeated for a second season and confirmed the conclusions based on the first experiment. The application, however, of these conclusions had to be restricted as they referred only to one area. Generalized conclusions for the Irrigation Scheme as a whole could only be obtained by repeating a similar experimental lay-out on areas in different parts of the Scheme within the same season. This communication presents the results of such out-station experiments made in the seasons 1932–3 and 1933–4, and a detailed experiment on the optimum spacing and date of thinning, carried out at Gezira Research Farm, is also included.

Owing to the difficulty of irrigation-control and supervision at out-stations, 'amounts of irrigation' was omitted, and, for similar reasons, the treatment-levels of other factors were also somewhat modified, but the same essential comparisons were retained. The experiments, therefore, comprised only the three factors of sowing-date, spacing, and nitrogenous manuring.

The most striking interrelations of these factors, as demonstrated by the results of the four-factor experiments already published, are:

1. Yield, both with and without nitrogen-application, has an optimal value for August sowing.
2. The returns in yield for nitrogen-application decline with advancing sowing-date (i.e. when cotton is sown successively later).
3. Spacing has little effect with early sowing, irrespective of nitrogen-application.
4. Spacing has a large effect with late sowing, irrespective of nitrogen-application.

OUT-STATION EXPERIMENTS IN THE GEZIRA

The series of out-station experiments outlined in the present paper was undertaken to ascertain how far the above conclusions could be applied to the Gezira Scheme as a whole, and also the extent to which these conclusions might require modifications as a result of local conditions.

The cotton plant is in general very susceptible to damage by disease and pests; and that grown in the Gezira is no exception. Further, owing to the varying rainfall in different areas of the Gezira, the extent of

interference in crop-development due to diseases and pests is very variable even within the same season. It is therefore essential to consider the effects of this interference when interpreting the yield data.

Treatments and lay-out.—The individual treatments compared were as follows:

Sowing-date	*Manure*	*Spacing*
1. *Early.* Aug. 7 2. *Middle.* Aug. 21 3. *Late.* Sept. 5	1. *Control,* no manure 2. *Manured,* 100 kg. ammon. sulphate per feddan*	1. *Close,* 30 cm. between holes 2. *Wide,* 60 cm. between 'holes' (2 plants per 'hole' in both cases; ridges 80 cm. apart)

* 1 rotl = 0·99 lb. = 0·45 kg. 1 feddan = 1·038 acres = 0·420 ha. 1 kantar seed-cotton = 315 rotls = 308 lb. = 141 kg.

It should be explained that in the Gezira cotton is sown on ridges, the seed being planted in shallow holes on the tops of the ridges.

The *actual* dates of sowing showed some variation owing to rain, &c., and in the yield table, therefore, these are given for each area separately.

The 12 treatments were replicated in 4 blocks (48 plots) in 1932–3 and in 5 blocks (60 plots) in 1933–4. For convenience in sowing, and to reduce marginal effects, the plots of the same sowing-date were grouped together in each block. Their positions within the block and their subdivisions for the 4 combinations of nitrogen and spacing were assigned at random

The range of sowing-dates and spacings employed in this series of experiments was smaller than in the four-factor experiments of 1929–30 and 1930–1 seasons, as it was desirable to approach more closely to the conditions pertaining to commercial cultivation. Similarly the amount of manure used was only a third of that in the earlier experiments. Consequently it is to be expected that the effects and interactions of the various factors will be less clearly defined.

The ammonium sulphate was applied a week *before* each sowing. This contrasts with the four-factor experiments, where applications were made at 4–6 weeks *after* sowing. The change in method was due to the results of Agricultural Section (Gezira Agric. Research Service) experiments at the Research Farm, which gave optimum responses to fertilizers when applied *before* sowing.

The 1932–3 Season Experiments

Notes on localities.—The sites of the experiments in 1932–3 season, and the distances in kilometres from the Gezira Research Farm (given in brackets), where the earlier experiments were undertaken, were (*a*) Qadd El Ein (66, North), (*b*) Ganneb (57, North), (*c*) Plot 79 Research Farm, and (*d*) Hag Abdullah (49, South). The Chemical Section (Gezira Agric. Research Service) reported as follows on the soils of these areas:

(*a*) *Qadd El Ein*: soil permeable, low salt-content: typical of the more fertile land in the north and west of the Scheme.

(*b*) *Ganneb*: soil permeability very poor, salt-content very high; typical of the poorer land generally.

(*c*) *Gezira Research Farm, Plot 79*: poorer land than the four-factor experiments

of 1929–30 and 1930–1 seasons, permeability rather poor, salt-content high; typical of much of the poorer land of the Central Gezira.

(*d*) *Hag Abdullah*: permeable, but salt-content rather high; characteristic of some of the poorer parts of the Southern Area.

In this season there was no experimental plot in the more northerly areas, nor in the better quality land to the west of the central Gezira area. Otherwise the soil conditions of the experimental plots were fairly typical of large areas of the Scheme.

Rainfall. The records from the rain gauge nearest to each experiment were:

Rainfall (in mm.), 1932

	Qadd El Ein (Toba Gauge)	*Ganneb* (Dolba Gauge)	*G. R. Farm*	*Hag Abdullah*
May . .	..	..	2	15
June . .	49	37	70	91
July . .	50	57	73	102
August . .	133	173	191	309
September .	27	50	35	75
October . .	..*	2	14	..
Total . .	259	319	385	592

* A localized rainfall of about 10 mm. occurred on the station but not at the Toba-Gauge area.

The increase in the rainfall from north to south is characteristic of the Gezira area, and is the main factor determining differences in pest-incidence and physiological development between the northern and southern areas. The rainfall figures also throw light on the distribution of the rainfall before or after the sowings of the various treatments. The totals approximated to the seasonal normal for each area.

Pests

Blackarm (*B. malvacearum*) was general in early and middle sowings of all experiments, but with considerable local variations in intensity. It checked early growth at Hag Abdullah; elsewhere the check was less severe earlier, but persisted and was more severe later, coincident with later rainfall in these areas. At Qadd El Ein the damage from Blackarm was particularly noticeable in late October when the plants were well grown.

There was a sudden attack of Thrips (*Hercothrips sudanensis*) in late October, and it was particularly severe on the late sowings at Ganneb and Hag Abdullah. The infestation was less severe where growth was dense (i.e. with close spacing).

Leaf-curl was general, and a '*Wilt*' caused losses in the late sowings at Ganneb. Further, *White Ants* affected the stand at G.R. Farm and at Hag Abdullah.

The 1933–4 Season Experiments

Notes on localities.—The sites of the experiments in 1933–4 were: Kab El Gidad (93 km. N. of Gezira Research Farm), Umm Degarsi (68 km. N.), Wad Husein (41 km. NW.), Plot 19 Gezira Research Farm, and Hag Abdullah (49 km. S.). No experiment was carried out at Ganneb; Kab El Gidad and Wad Husein were new areas, and that at Umm Degarsi was 2 km. from Qadd El Ein.

The Chemical Section (Gezira Agric. Research Service) reported as follows on the soils of these experimental areas:

1. *Kab El Gidad*: soil slightly inferior to that of Research Farm; found mainly in the northern extension of the irrigated area. Total nitrogen appears to be rather low; average clay-content 50 per cent.
2. *Umm Degarsi*: soil resembles and is superior to that of Research Farm; capillary-rise results for second foot are unusually high; probably more permeable

than most of the Gezira. Total nitrogen appears to be rather low; clay-content 50 per cent.

3. *Wad Husein*: soil resembles but is slightly superior to that of Research Farm; capillary-rise results for second foot unusually high; probably fairly permeable. Total nitrogen apparently normal; average clay-content 50 per cent.
4. *Gezira Research Farm, Plot 19*: soil typical of the Research Farm; much resembles that of the central part of the irrigated area; clay-content 56 per cent.
5. *Hag Abdullah*: soil differs slightly from that of Research Farm in salt-distribution, and also in capillary-rise of subsoil samples, which is low; resembles other plots in Hag Abdullah Block; is superior to soil of the Research Farm. Total nitrogen apparently rather high; clay-content 63 per cent.

Rainfall. The rainfall recorded at the rain-gauge nearest to each experiment, and in no case more than 2 km. distant, was as follows:

Rainfall (in mm.), 1933

	Kab El Gidad	*Umm Degarsi*	*W. Husein*	*G. R. Farm*	*Hag Abdullah*
May . .	9	. .	8	31	63
June . .	104	63	81	35	86
July . .	24	67	39	81	114
August .	178	125	106	117	229
September .	11	9	87	52	29
October .	. .	7	5	36	13
November .	. .	. .	1	1	. .
Total .	326	271	327	353	534

Pests

Blackarm (*B. malvacearum*) was severe in some areas and light in others. *All* sowings at Wad Husein suffered damage, particularly the earliest. On the remaining areas, Blackarm was general on the first and second sowing-dates; it was more severe at the Research Farm, but slight only at the two northern stations.

Thrips (*Hercothrips sudanensis*) damage was again severe. The second and third sowings at Hag Abdullah were seriously damaged by Thrips infestation, heavy leaf- and bud-shedding resulting in an extensive check in development. Thrips were also general on the second and third sowings at Umm Degarsi and Kab El Gidad, but the damage was only slight.

White Ant damage produced irregular stands at Hag Abdullah and the Research Farm as in the previous season. *Leaf-curl* developed considerably later and was much lighter and of little effect compared with 1932–3 season. *American Boll-worm* (*Heliothis obsoleta*) produced heavy early fruit-shedding in September and October at Wad Husein and to a lesser extent at Umm Degarsi. The damage at Wad Husein permanently affected the crop, the pickings being much later there than elsewhere, owing to the shedding of the early fruits which would otherwise have produced the crop.

In addition to disease-damage at Hag Abdullah a close succession of rain showers in late August, with the associated high humidity, resulted in waterlogging of the crop in *both* seasons. The first and second dates showed leaf-yellowing, and the cotyledons and first leaves were prematurely shed. Stem development was also retarded. When the soil dried out after waterlogging had ceased, the plants returned quickly to normal colour, but were much smaller than usual for their age. In this season the experimental sites were more representative of the whole Gezira area and were fairly typical of the separate areas, with the possible exception of some poorer soils represented by the Ganneb experiment in the previous season.

The rainfall totals per station for this season were similar to those for the previous season, with the exception of the heavy rainfall in late June at Kab El Gidad.

Final Yields of Out-station Experiments

The final yields of seed-cotton for the separate treatments are given in Tables 1 and 2 for the seasons 1932–3 and 1933–4, respectively. The treatment-yields are given in columns under the headings of the separate experiments.

TABLE 1. *Final Yields from Out-station Experiments, 1932–3*

(in kantars per feddan of seed-cotton)

Treatments			*Stations*				
			Dolga Block				
Sowing	*Spacing*	*Manure*	*Qadd El Ein*	*Ganneb*	*G. R. Farm*	*Hag Abdullah*	*Average all Stations*
August 8–12	30 cm.	No manure	2·60	1·95	1·59	2·26	2·10
	30 ,,	Manured	2·79	2·10	2·34	3·37	2·65
	60 ,,	No manure	2·58	1·75	1·52	1·96	1·95
	60 ,,	Manured	3·11	2·23	2·03	2·28	2·41
	Average		2·77	2·01	1·87	2·47	2·28
August 20–8	30 cm.	No manure	3·05	2·14	2·13	1·50	2·21
	30 ,,	Manured	4·08	2·58	2·58	1·86	2·77
	60 ,,	No manure	2·80	1·73	1·57	0·68	1·70
	60 ,,	Manured	3·49	2·19	2·26	1·28	2·31
	Average		3·36	2·16	2·14	1·33	2·34
Sept. 5 .	30 cm.	No manure	2·96	1·96	1·81	1·45	2·05
	30 ,,	Manured	3·60	2·15	2·63	1·45	2·46
	60 ,,	No manure	2·35	1·34	1·19	0·78	1·42
	60 ,,	Manured	2·56	1·45	1·61	0·91	1·63
	Average		2·87	1·73	1·81	1·15	1·89
	Average all		3·00	1·96	1·94	1·65	2·14

TABLE 2. *Final Yields from Out-station Experiments, 1933–4*

(in kantars per feddan of seed-cotton)

Treatments			*Stations*					
Sowing	*Spacing*	*Manure*	*K. El Gidad*	*Umm Degarsi*	*Wad Husein*	*Research Farm*	*Hag Abdullah*	*Average all stations*
August 6–11	30 cm.	No manure	3·15	3·49	4·15	2·91	3·57	3·45
	30 ,,	Manured	3·52	3·78	3·86	2·82	3·79	3·56
	60 ,,	No manure	2·56	2·93	3·86	1·98	3·05	2·88
	60 ,,	Manured	3·08	3·16	4·07	2·38	3·78	3·33
	Average		3·08	3·34	3·98	2·37	3·55	3·30
August 20–4	30 cm.	No manure	2·93	3·13	3·80	2·41	1·80	2·81
	30 ,,	Manured	3·23	3·26	4·23	2·55	3·26	3·31
	60 ,,	No manure	2·34	2·56	3·57	2·23	1·43	2·43
	60 ,,	Manured	2·61	2·74	3·93	2·34	2·60	2·84
	Average		2·78	2·93	3·88	2·38	2·27	2·85
Sept. 4–6 .	30 cm.	No manure	2·68	2·92	3·63	2·41	1·88	2·71
	30 ,,	Manured	2·88	2·97	4·10	2·87	2·72	3·11
	60 ,,	No manure	2·18	2·32	2·82	1·61	1·37	2·06
	60 ,,	Manured	2·20	2·28	3·33	2·32	2·13	2·45
	Average		2·49	2·62	3·47	2·30	2·02	2·68
	Average all		2·78	2·96	3·78	2·42	2·62	2·91

The 'significances' of the treatment responses are presented in Table 3. In view of the large variations in yields, due to disease, &c., it is essential to consider the interaction effects in relation to their statistical significance.

TABLE 3. *Summary of the 'significant' Treatment-differences as estimated by the Analysis of Variance*

	1932–3					*1933–4*					
	Q. El Ein	*Gan-neb*	*G.R.F. P. 79*	*Hag Abd.*	*Aver-age*	*K. El Gidad*	*Umm De-garsi*	*Wad Husein*	*G.R.F. P. 19*	*Hag Abd.*	*Aver-age*
Sowing date .	..	S	S	SS	SS	SS	SS	..	..	SS	SS
Nitrogen . .	SS	SS	SS	SS	SS	SS	S	S	SS	SS	SS
Spacing . .	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Sowing and Nitrogen . .	S	..	..	..	S	S	..	..	..	S	..
Sowing and Spacing	SS	SS	SS	..	SS	..	..	S	..	..	S
Nitrogen and Spacing . .	..	..	..	..	..	..	..	..	..	..	..
Sowing, Nitrogen, and Spacing .	SS	..	..	..	..	..	..	..	..	..	..

Note: 'S' = The experimental z value exceeded the 5 per cent. probability value.
'SS' = The experimental z value exceeded the 1 per cent. probability value.

(1) *Effect of Single Factors*

The effects of the single factors were obtained by averaging the yields of all treatments in which the particular factor is maintained at a particular level, irrespective of the levels of the other factors.

(*a*) *Sowing-date.*—The results for sowing-date are given in Table 4:

TABLE 4. *Yields and Sowing-dates*

(kantars per feddan)

		Sowing I	*Sowing II*	*Sowing III*
1932–3	*Position*	*Aug. 8–12*	*Aug. 20–8*	*Sept. 5*
Qadd El Ein . .	North	2·77 (100)	3·36 (121)	2·87 (104)
Ganneb . . .	North	2·01 (100)	2·16 (107)	1·73 (86)
Gezira Res. Farm .		1·87 (100)	2·14 (114)	1·81 (97)
Hag Abdullah . .	South	2·47 (100)	1·33 (54)	1·15 (47)
1933–4	*Position*	*Aug. 6–11*	*Aug. 20–4*	*Sept. 4–6*
Kab El Gidad . .	North	3·08 (100)	2·78 (90)	2·68 (81)
Umm Degarsi . .	North	3·34 (100)	2·93 (88)	2·62 (78)
Wad Husein . .	NW.	3·98 (100)	3·88 (98)	3·47 (87)
Gezira Res. Farm .		2·57 (100)	2·38 (93)	2·30 (89)
Hag Abdullah . .	South	3·55 (100)	2·27 (64)	2·02 (57)

The figures in brackets represent the yields of the second and third sowings as percentages of the first sowing, for each experiment. Hag Abdullah in both seasons showed a pronounced optimum at the earliest sowing: the latest sowing actually gave only half the yield of the earliest sowing. In view of the severity of Thrips damage there in both seasons on all except the earliest-sown cotton, it is impossible to decide how much

other factors peculiar to the Hag Abdullah area contributed to this pronounced optimum yield from early sowings.

Although in some cases yields due to different sowing-dates did not differ significantly, it will be seen that all the areas, excepting Hag Abdullah, show a similar trend within the same season. Between seasons, however, the optimal sowing-date shows considerable variation. Thus the second sowing was optimal in 1932–3 and the first optimal in 1933–4 season. This superiority of the first sowing in the latter season was more marked in the two northern experiments than elsewhere. Apart from this, the sowing-date differences at the Research Farm appear to give a reliable indication of the optimum for the remainder of the Gezira Scheme in the same season.

The four-factor experiments of 1929–30 and 1930–1 seasons included only one sowing in August. So far as comparisons can be made, the present series of experiments confirms that the optimum date of sowing is in August, but indicates that a more exact definition of the optimum must include consideration of the particular seasonal characteristics. This aspect is discussed later.

(*b*) *Spacing*.—The results for the spacing comparisons are included with those for manuring in Table 5 (*a*).

TABLE 5. *Yields for Comparisons of (a) Spacing and (b) Manuring*

(kantars per feddan)

	(*a*) *Spacing*			(*b*) *Manuring*		
Experiment	*Close*	*Wide*	*Increase with close*	*Nil*	*Ammon. sulph.*	*Increase with ammon. sulph.*
1932–3						
Qadd El Ein (N.)	3·18	2·82	0·36	2·72	3·27	0·55
Ganneb (N.) .	2·15	1·78	0·37	1·81	2·12	0·31
Research Farm .	2·18	1·70	0·48	1·64	2·24	0·60
Hag Abdullah (S.)	1·98	1·32	0·66	1·44	1·86	0·42
1933–4						
Kab El Gidad (N.)	3·06	2·50	0·56	2·64	2·92	0·28
Umm Degarsi (N.)	3·26	2·66	0·60	2·89	3·03	0·14
Wad Husein (NW.)	2·66	2·17	0·49	2·26	2·58	0·32
Research Farm .	3·96	3·59	0·37	3·64	3·92	0·28
Hag Abdullah (S.)	2·84	2·39	0·45	2·18	3·05	0·87

The results in all experiments illustrate the superiority of close spacing over wide spacing, when comparing the yields obtained by averaging the remaining treatments. This agrees with the results of the four-factor experiments, in which, with a still closer spacing (25 cm. between holes), the closest spacing employed was the optimum.

(*c*) *Nitrogen-response*.—The responses to applications of ammonium sulphate are shown in Table 5 (*b*). In all the experiments the manure gave increases in yield, when comparing the averages of other treatments. The Hag Abdullah response is abnormally great in 1933–4, but, otherwise, the yield data do not indicate any general geographic trend over the

Gezira Scheme in the degree of manurial response and, therefore, of soil-nitrogen supply.

Nevertheless the developmental data do indicate a variation in nitrogen response, and presumably, therefore, had disease-damage been negligible, a similar variation would have been demonstrated in the final yields. It is impossible to attach much importance to the abnormally great response to manuring at Hag Abdullah in view of the interference of local factors whose effects have not yet been precisely defined, viz. severe thrips-infestation, and extensive waterlogging of the soil in late August by heavy rainfall.

(2) *The Interactions of the Factors*

Owing to the large error in measuring interaction-effects as compared with errors for single factors, the yields of the separate stations have been totalled to give the average interaction-effects.

(*a*) *Sowing-date and nitrogenous manuring.*—The following table shows the mean interaction-effects over all the experiments for sowing-date and nitrogen-comparisons:

TABLE 6. *Yields for Sowing-date and Nitrogen*

(kantars per feddan)

	1932–3			*1933–4*		
	Sow. I	*Sow. II*	*Sow. III*	*Sow. I*	*Sow. II*	*Sow. III*
Nil	2·03	1·96	1·74	3·16	2·62	2·38
Manured	2·53	2·54	2·05	3·44	3·07	2·78
Increase	0·50	0·58	0·31	0·28	0·45	0·40

The four-factor results showed that the response to manure was greatest with early sowings and progressively decreased with delay in sowing-date. The results of the 1932–3 season showed smaller responses for September sowings than for August sowings, but the optimum response actually occurred with the later August sowing. In the 1933–4 season the response to manuring was least with the earlier sowing. Thus the partial confirmation of the four-factor results obtained in the first season was not borne out in the second season, but no exact comparison can be made, as the dates of application of manure were different, i.e. some weeks *after* sowing in the four-factor experiments, and *before* sowing in out-station experiments. (The possible effects of these differences are discussed later.) The significant interaction, shown in Table 3, for Qadd El Ein in the 1932–3 season is of the same type as shown in the average of all stations given above. In 1933–4 the two northern stations, Kab El Gidad and Umm Degarsi, on the other hand, showed interactions of the 'four-factor' type, the response being greatest for the earliest sowing and least for the latest sowing: only the former was statistically significant. The Hag Abdullah results showed a more pronounced interaction between nitrogenous manuring and sowing-date than elsewhere,

the superiority of the response at the second date over that at the first date being particularly marked. The average interaction-effects of the 1933–4 season, shown in Table 6, are to a large extent determined by the very marked effects at Hag Abdullah. In the only areas where disease-damage was light, i.e. in the north of the experimental areas, the interaction is of the form established in the four-factor experiments. Hence it is concluded that there are indications of a general interaction-effect throughout the Scheme of a type similar to that obtained in the four-factor experiments, but that differential disease and pest-damage in the different sowing-dates may alter considerably the nature of the interaction.

(*b*) *Sowing-date and spacing.*—The average interaction-effect over the series of experiments in each season for sowing-date and spacing-comparisons are as follows:

TABLE 7. *Yields for Sowing-date and Spacing*

(kantars per feddan)

	Season 1932–3			*Season 1933–4*		
	Sow. I	*Sow. II*	*Sow. III*	*Sow. I*	*Sow. II*	*Sow. III*
Close . .	2·38	2·49	2·26	3·50	3·06	2·91
Wide . . .	2·18	2·01	1·53	3·10	2·63	2·25
Difference . .	0·20	0·48	0·75	0·40	0·43	0·66

Both seasons showed a superiority of close spacing at all dates of sowing, and this superiority increased with successively later sowings. The interaction was less pronounced in 1933–4 owing to the marked increase in yield following close spacing with even the earliest sowings. The significant interactions shown in Table 3 are all of the type indicated by the general averages above. The interaction at Qadd El Ein was particularly marked, as the yield of the earliest sowing with the *wide* spacing was greater than that with the close spacing.

Thus the increased response to closer spacing with delayed sowing-date established in the four-factor experiments for the Gezira Research Farm was confirmed in all experiments in both seasons, and may therefore be regarded as finally established for the whole area at present under irrigation.

(*c*) *Interactions between sowing-date, nitrogenous manuring, and spacing.*—As shown in Table 3, the Qadd El Ein Experiment in 1932–3 showed a significant second-order interaction between the factors, but, owing to lack of confirmation from other experiments, little importance can be attached to this result. Examination of the individual treatment-yields shows that this interaction results from a manurial response, which is greater with *wider* spacing for early-sown cotton, and with *closer* spacing for middle and later-sown cotton. It may be due to Blackarm damage, which was extensive on the early-sown cotton at Qadd El Ein, and has been shown to be more severe on closer-spaced plants [2].

The Spacing, Date-of-thinning, and Date-of-sowing Experiment, G.R. Farm (P. 34–5), 1932–3

Additional information on the importance of changes in optimum spacing in relation to sowing-date is available from a large-scale experiment carried out on the Gezira Research Farm in the 1932–3 season. This experiment also included 'date of thinning' the plants as one of the factors, since it is clear that a change in this date may change the optimum spacing.

Treatments and lay-out.—The 10 spacing treatments comprised comparisons of 1, 2, 4, 6, 8, and 16 plants per metre ridge, with different combinations of numbers of plants per hole. These spacings were repeated at two sowing-dates (Aug. 12 and Sept. 2), and at each spacing thinnings at 3 or 6 or 9 weeks after sowings were compared. Thus each plot was thinned in one operation from about 10 plants per hole (usual after normal field-germination) to 1, 2, or 4 plants per hole, according to the particular treatment. The 60 treatments were replicated four times, in four randomized blocks, making a total of 240 plots on an area of 10 feddans.

For convenience in cultivation and to obtain the largest numbers of replications for the comparisons which were expected to produce the smallest differences, i.e. dates of thinning, the treatments were arranged so that within each block (1) the plots of one sowing-date were grouped together, (2) the 10 spacing-treatments were scattered at random within each group of sowing-date plots, and (3) each unit for spacing-comparisons was subdivided into three to comprise the three dates of thinning-treatments, assigned at random. Thus the effective replication for the single-factor comparisons was: eightyfold for dates of thinning, eightfold for spacing, and fourfold for dates of sowing.

The following is a summary of the statistical analysis of the results:

	'Z' Value			
	Experimental	*5 per cent.*	*1 per cent.*	
1. Sowing date	0·73	1·16	..	Not Sign.
2. Spacing	1·86	0·37	0·52	Highly Sign.
3. Date of thinning	1·52	0·55	0·76	,, ,,
4. Sowing-date and spacing	0·85	0·37	0·52	,, ,,
5. Sowing-date and date of thinning	0·92	0·55	0·76	,, ,,
6. Spacing and date of thinning	0·71	0·24	0·34	,, ,,
7. Sowing-date and spacing and date of thinning	0·02	0·25	..	Not Sign.

All the single factors and first-order interaction-effects are highly significant except that of sowing-date.

The general level was well above the average for the Research Farm and the crop fortunately escaped serious pest-damage, other than by Thrips infestation. The latter caused extensive leaf-shedding in the wider-spaced plants of the later sowing in November, and therefore part of the increased yield with closer spacings must be attributed to relatively less Thrips damage. There was, in addition, a differential effect

of Thrips on the thinning-dates of the late sowing, the latest thinning being less affected than the two earliest thinnings.

(*a*) *The yields from the various spacings.*—The yields from the 10 spacing-treatments for each sowing-date are compared in Table 8, where full details of the plants per hole and holes per ridge are also given.

TABLE 8. *Yields of Spacings at two Sowing-dates*

(kantars per feddan)

Number of Plants per metre ridge	1	2		4			6	8		16
Number of holes per metre ridge	1	2	1	4	2	1	2	4	2	4
Number of plants per hole	1	1	2	1	2	4	3	2	4	4
Yields										
August-sown	1·62	2·48	2·20	2·78	2·96	2·81	3·18	3·05	3·08	3·15
September-sown	0·94	1·43	1·49	2·36	2·35	2·08	2·88	3·24	3·12	3·70
Yields of August minus yields of September	+0·68	+1·05	+0·71	+0·42	+0·61	+0·73	+0·30	−0·19	−0·04	−0·55
Average of August-sown	1·62	2·34		2·85			3·18	3·07		3·15
Average of September-sown	0·94	1·46		2·26			2·88	3·18		3·70

With both sowing-dates the widest spacings employed gave the lowest yields; but whereas with the August sowing the yield of the widest spacing was 51 per cent. of that of the optimum spacing, with the September sowing the yield was only 25 per cent. of the optimum. Further, with progressively more plants per metre ridge, the August sowings showed little increase in yield with more than 6 plants per ridge: whereas with September sowing the yields increased uniformly with closer spacing, so that the closest spacing employed gave the maximum yield; and there were indications that the optimum number of plants per metre ridge was considerably greater than the highest number per ridge included in the experiment.

This remarkable contrast between August and September sowings fully confirms the results both of the four-factor experiments and of the series of experiments already described in the present paper, within the restricted limits determined by the range of spacings employed. It is also apparent that had the numbers of plants per hole in these experiments been increased above the normal two plants, the response to closer spacing with September sowings would have been still more marked.

Some light is thrown on the mechanism involved in the spacing and sowing-date interactions by considering the results of the yields corresponding to the various dates of thinning in relation to spacing and sowing-date.

The following are the yields for the three dates of thinning for comparisons of number of plants per hole for a spacing of 50 cm. between holes, for each sowing-date:

TABLE 9. *Yields given by Different Dates of Thinning with Different Numbers of Plants per hole*

(kantars per feddan)

Plants per hole		*Sown Aug. 12*				*Sown Sept. 2*			
		1	*2*	*3*	*4*	*1*	*2*	*3*	*4*
Thinned at	3 weeks	2·90	3·13	3·49	3·24	1·45	2·42	2·92	3·07
	6 weeks	2·59	3·07	3·21	2·96	1·41	2·19	2·97	3·07
	9 weeks	1·93	2·69	2·83	3·03	1·43	2·42	2·75	3·21

The above figures show that, with August sowing, the best yields are obtained with early thinning, and the differences are particularly marked when thinning is drastic, i.e. to one plant per hole. The date of thinning was of little importance in late sowing as compared with early sowing, and these results provide the interpretation of the spacing and sowing-date interaction. It is obvious that the late-sown plants, owing to greater individual plant-development, are unable to compensate to any marked degree for the fewer plants existing with wider spacing, or to respond to early thinning. Consequently it is of less importance when these plants are thinned, the yield being primarily determined only by the *number of plants remaining* after thinning.

With August sowings the plants are able to compensate extensively for any decrease in the number of plants. The number of plants per unit area is therefore not of great importance in determining final yield with such sowings, if thinning to the final stand is early enough to enable the plants remaining to have sufficient time for the additional compensating growth to be produced. This is clearly brought out from the yield figures given earlier; with early thinning the yield with one plant per hole is 90 per cent. of the yield with four plants per hole, whereas with late thinning, and therefore a reduced growing-period after thinning, the single plants produce a yield which is only 64 per cent. of that with four plants per hole.

In the four-factor experiments the main thinning was at four weeks after sowing and in the series of out-station experiments at three weeks after sowing. Hence, in all these experiments, the thinning was sufficiently early to allow of compensation by the wider spacings. The tendency was for August-sown plants to show small differences in yields between spacings. On the other hand the September sowings, where compensation was very slight, produced large differences between spacings, the greater number of plants per unit area with the closer spacing producing the greater yield. Thus an interaction is produced between 'spacing' and 'sowing-date'.

It should be noted that Blackarm was negligible in this experiment; if it had not been, some of the results might have been modified owing to differential sowing-date and spacing-effects [2].

AN ADDITIONAL EXPERIMENT ON SPACING, THINNING, AND SOWING-DATE. HAG ABDULLAH, 1933–4

The interrelation of spacing and thinning with the date of sowing has been further studied in another experiment on a smaller scale at Hag Abdullah carried out in 1933–4, which gave the following yields (kantars per feddan):

Three-factor Experiment on Spacing, Thinning, and Sowing-date

	Sown Aug. 6	*Sown Sept. 6*
A Spacing 30 cm., no thinning	4·35	4·36
B ,, 30 cm., 4 plants per hole	4·54	3·66
C ,, 60 cm., 2 ,, ,, ,,	2·89	1·61
D ,, 60 cm., 1 plant ,, ,,	3·01	1·07

(Sowings were planted on ridges at 80 cm. apart.)

From 3 replicates per treatment, each plot = 1/22nd feddan
z value for significance of *thinning* = 1·85 (5 % = 0·63).
z value for significance of *sown* versus *thinning* = 0·76 (5 % = 0·63).

The statistical analysis gave highly significant results for 'thinning', and a significant interaction of sowing and thinning. The results agree with those of a comparable character in the main spacing-experiment described above and extend the range of this experiment in an important respect. The 'no-thinning' treatment of the September sowing not only gave yields almost equal to the maximum for the August sowing, but also showed a highly significant superiority in yield over the four plants per hole, 30 cm. spacing treatment, which was the densest spacing tested in the main experiment.

From these results it is concluded that with late sowings higher yields than are usually obtained could be realized by less drastic thinning than has previously been tested and, in fact, that no thinning at all might give the maximum yield.

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FURTHER EXPERIMENTS ON THE INTERRELATION OF FACTORS CONTROLLING THE PRODUCTION OF COTTON UNDER IRRIGATION IN THE SUDAN

Pt. II. RESULTS AND CONCLUSIONS

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THE results of the experiments outlined earlier in Part I (this *J.*, 1935, 3, 276) adequately confirm several of the conclusions based on the results of the four-factor experiments which preceded them, and the remaining conclusions from the latter experiments, based on the three factors common to all experiments, have not been refuted. There are also indications that these remaining conclusions would have been confirmed had damage by disease not modified the relative treatment-differences and also increased variation between plots of the same treatment.

The effects of diseases and pests on growth and yield are complex and varied. The Wad Husein experiment, despite the heaviest damage from Blackarm and American boll-worm, produced the greatest yields of all the experiments. It was evident from investigations on this experiment that interaction-effects between various types of plant-damage were frequent and extensive. Thus Blackarm destroyed much of the early growth of leaves, branches, and early fruits: heavy shedding of early fruits also occurred as a result of American boll-worm. The combined effect of the simultaneous leaf and early-fruit shedding was to allow the plant to resume extensive vegetative growth late in the season at a time when normally the growth would be terminated by *internal limitation due to boll-development*. The later growth was produced after the phase of pest-damage had ended, and resulted in a large, but late-maturing, final crop; this late crop is possible in the Sudan Gezira, as there is no early curtailment of the picking-season by Pink Boll-worm, such as occurs in Egypt.

The effects of damage by Blackarm may be important in relation to manurial response. Following a nitrogenous manuring, the leaves show a maximum response at a definite interval after the application; this response may be one of increase in leaf-size or number, or of increase in internal nitrogen-concentration. Where manures are applied before sowing, as in the out-station series of experiments, the maximum response usually coincides with the greatest Blackarm damage, and therefore considerable reduction in manurial response may be shown in the final crop. Thus Blackarm may be partly responsible for the smaller response to manuring with early-sown cotton in the out-station series, as compared with the corresponding response recorded in the four-factor experiments, in which manures were applied from 1 to 2 months after sowing.

The effects of Thrips-damage on the various treatments may differ considerably from the effects of Blackarm, although in both cases premature leaf-destruction is the dominant feature. Thrips-infestation occurs later in the season than Blackarm, and consequently affects the crop at a later stage of growth. This also may be important in relation to manurial response, since some additional growth, resulting from the manuring, will have occurred before the onset of Thrips. Therefore it is improbable that Thrips will appreciably reduce the response to manuring. Thrips-infestation varies markedly with the spacing of the crop, being much more extensive on widely, than on closely, spaced plants. This again contrasts with the nature of the Blackarm damage, for, as already mentioned, this damage is usually more severe on closer, than on wider, spacings.

Summarizing the effects of Blackarm and Thrips on the interaction of manuring and spacing with sowing-date, it appears that Blackarm may reduce the manurial response and the value of close spacings with early sowings, without having any appreciable effect on later sowings, whereas Thrips damage is usually confined to later sowings and, whilst not interfering appreciably with the response to manuring, it still further emphasizes the superiority of close spacing.

Unlike the other main pests, Blackarm and Thrips, which destroy or damage the plants, Leaf-curl apparently only causes distortion of the plant-organs. No reliable measure of the effects of Leaf-curl on yield has yet been made on a field scale, since the severity of Leaf-curl infection is correlated with the vigour of the crop, the more vigorous growth being associated with greater infection [1]. Although no accurate measurement can be made of loss in crop from the disease, counts of numbers of plants infected are some guide in estimating the depressing effect of the disease. As infection only becomes appreciable from October onwards, it follows that the extent of damage by Leaf-curl is greatest on late sowings, since they are affected at an earlier stage of growth. Moreover, manured plots and wide spacings are more affected than non-manured and close spacings, since growth continues later in the former treatments.

Counts of numbers of plants infected in the out-station experiments in the 1932–3 season, when Leaf-curl was general, showed differences between the different stations, as well as well-marked differences within any one station. Yet, when corresponding yields were examined, no differential effects of the same character were evident. In this connexion it is of interest to compare the yields for the 1932–3 season, when Leaf-curl was general, with the corresponding yields in 1933–4, when Leaf-curl was comparatively negligible. In no case is it possible to ascribe any differences between the two seasons in the nature of the interactions of the treatments to the different degrees of Leaf-curl infection.

The 'Wilt' at the Ganneb Station occurring in early November 1932–3 had a differential incidence on the treatments of the late sowings. An average of 11 per cent. of the plants was either killed or severely affected, whilst the two earlier sowings had only negligible losses. The wide-spacing and manured treatments of the sowing had approximately

double the losses of the close-spacing and non-manured treatments. The reasons for these differential effects are as yet unknown.

In respect of the four pests referred to above, it will be noted that three of these—Thrips, Leaf-curl, and Wilt—tend to have the greatest incidence on the September sowing; also on the wide spacing and, to a less degree, on manured treatments of this sowing. These cumulative effects accentuate the differences in yields between the late and earlier sowings, and, more particularly, depress the yield of the wide spacing and reduce the effects of manuring for late sowing. The middle sowing, on the other hand, which is nearest to the optimum, had the lightest pest-incidence of any sowing tested.

An interaction between spacing and sowing-date, where close spacings are particularly advantageous with later sowings, appears to be general throughout the Gezira Scheme in all seasons. The existence of such an interaction might be anticipated were there a short growing-season, for the additional plants with close spacing make up for the shortened season due to later sowing. Since the picking season in the Gezira Scheme can extend over four months, it appears that there should be sufficient time for the later sowings to mature within the picking season. In point of fact, only in the first two months are the pickings heavy, and it can only be concluded that, despite the length of the total period when the cotton crop is in the ground, the effective growing-period is restricted to the earlier months, and the delay consequent upon sowing in September, instead of in early August, represents a serious curtailment of the period of favourable conditions for rapid early growth. The results show that September-sown plants are unable to compensate by greater individual plant-growth for the greater volume of soil available per plant with wider spacing. Hence, whereas a range of spacings, producing different numbers of plants per unit area, may with mid-August sowings give similar yields, with September sowings the yields increase with increase in numbers of plants per unit area, whether they are arranged in closer-spaced holes or as more plants per hole. Developmental data show that, throughout the main growing-period, the later (i.e. September) sowings have a higher leaf-to-stem ratio than the earlier sowings. This is due to restricted branch-development with later sowings. This restriction destroys the principal compensating mechanism of the plant for utilizing wider spacing, and establishes the importance of plant-number with the restricted branching of later sowings. It was suggested, in discussing the four-factor experiments, that early sowings were limited by nitrogen-supply, and that later sowings were controlled by an aerial factor, i.e. the high temperatures experienced in their early stages of growth. It is possible, therefore, that the temperatures are indirectly responsible for the reduced branch-development; this will be discussed in a subsequent paper.

It is apparent that the optimum sowing-date varies in different seasons; it was earlier in season 1933–4 than in season 1932–3. Associated with this variation in optimum is a change in the extent to which the earlier sowings compensate for wider spacing. In the four-factor experiments of the 1929–30 and 1930–1 seasons the compensation was almost complete.

In the 1933–4 season, on the other hand, in all experiments except Wad Husein, the superiority of close spacing was pronounced at all dates of sowing. It would appear to be a natural extension of the hypothesis that high temperatures limit early growth to suggest that the varying degrees of compensation possible with wider spacings are controlled by corresponding local and seasonal variations in temperature.

The large seasonal variations of yields of all treatments, indicated by the present series of experiments, together with the two four-factor experiments already described, have evoked considerable discussion, particularly as similar extensive annual fluctuations occur in the Gezira yields as a whole. It is evident that disease plays an important role in determining these yields and, whilst disease-damage remains general, it is difficult to establish the precise nature of any physiological determination which may operate in addition to disease.

That the rainfall in May and June exerts a depressing effect on yields of cotton sown in the following July or August was established by E. M. Crowther [2] on yield figures alone. Recently some confirmation has been given of this relationship by the result of a small experiment in which screening the land from early rainfall resulted in an increased yield. Hewison [3] has shown that greater annual rainfall is associated with lower yields, and vice versa. The rains later in the season also exert varying influences on yield that include the more obvious effects, such as the growth check at Hag Abdullah, due to standing water following heavy rain, and the spread of Blackarm by October rain-showers. It must be admitted that the less obvious effects of the main and late rains, together with those due to the early rains, have not so far been adequately explained. Greene [4] suggests that the optimum sowing-date is determined by the distribution of the rainfall in any season, the optimum being early in the seasons of early rainfall, &c., and he has experiments in progress designed to elucidate this relationship.

Other suggestions include the possible interference with soil cracks by the early rainfall, either by reduced rate of drying out of the soil [5], or by direct closure of the sub-soil cracks by the early rainfall [6]. Both these suggestions assume that thorough cracking of the sub-soil is essential to obtain adequate sub-soil aeration or water-penetration.

Considering the experimental results as a whole, it is concluded that these have not only given information of value with reference to the specific aims of the experiments, but have been illuminating in other respects also.

In the first place, the experimental results obtained in the original four-factor experiments at the Research Farm have been found to apply generally to other areas in the Gezira, with, however, some modification due to varying seasonal factors and pest-incidence. It is concluded, therefore, from the foregoing that the experimental results obtained at the Research Farm, in so far as they have been tested by the out-station experiments in these two years, have had a general application already noted.

Secondly, with regard to the above-mentioned modification, the out-station experiments have made possible comparison of the development of plants under identical treatments but varying soil, meteorological en-

vironment, and pest-incidence, with the final yields which followed these varying conditions. The experimental results described in this paper have therefore emphasized the importance of keeping a record of the conditions under which the crop develops, in order to understand the causes which have produced the final yield differences.

Agricultural Value of the Results

The importance of close spacing to obtain the maximum yields with late sowings has been brought out very clearly in all the results considered. The pronounced increases in yields produced by closer spacings for such sowings are of obvious agricultural importance.

The results show clearly that in order to obtain the maximum yields possible with late sowings it is necessary to have a denser population of plants per unit area than has yet been attempted under normal cultivation. The practice of leaving two plants per 'hole' for early sowings is supported by the experimental evidence. The data presented, however, indicate strongly that late sowings require both closer spacing between 'holes', and also more than two plants per 'hole', to give the maximum yields possible. The results of the multiple-factor spacing-experiments quoted indicate, in fact, that with late sowings all thinning may be abandoned with beneficial results, even with a 25-cm. spacing between holes.

The results, too, have shown that close spacing for late sowing tends to lessen pest-damage, to which these sowings appear specially liable. It also acts as an insurance against excessive reduction in crop due to stand losses.

For earlier sowings a somewhat close spacing has generally given the highest yields; it may also prevent crop-reduction from stand losses.

The degree of response to applications of ammonium sulphate remains problematical when disease and pest-damage may be general. In the four-factor experiments a definitely maximal response was obtained with the earliest sowings, but in the out-station experiments no well-defined relationship was apparent between manurial response and date of sowing of the crop.

No conclusion can be drawn as to an optimum date of sowing, except for Hag Abdullah, in which the earliest sowing gave the maximum yield in both seasons. The probability of variation in pest-incidence in other years, however, indicates the need of caution in accepting this sowing-date as the optimum for other seasons.

No consideration has been given to any differential effects of the treatments tested on ginning out-turn and quality of the lint. These will be referred to in a later paper, and only a brief reference is made here.

In general, a tendency towards lower quality with pickings later in the season has been a regular characteristic in all seasons, only partially off-set by an increase in the ginning out-turns. The cotton produced by a late sowing, therefore, owing to the greater proportion of later-picked cotton, is generally of lower average quality than for earlier sowings. Closer spacing, which increases the proportion of the crop obtained in the earlier pickings, tends to increase the proportion of the better-

quality cotton, whilst wider spacings and manure tend to produce the reverse effect, by increasing the amount obtained in late pickings.

It should be noted that these spacing and manurial effects apply more particularly to later sowings, as the quality of the cotton tends to fall more rapidly with pickings later in the season. As sowings are progressively earlier, however, spacing and manurial effects of this character are complicated by other factors, more particularly Blackarm, and may not produce results similar to those for the late sowings.

Summary of Parts I and II

Field experiments are described which were designed to test whether conclusions drawn from experiments made on the Gezira Research Farm are applicable over the large areas of cultivation included under the Gezira Irrigation Scheme.

Four experiments were undertaken in 1932–3 and five in 1933–4. In each experiment comparisons were made of sowing-dates, spacings, and nitrogenous manuring in different combinations.

The marked superiority of closer spacing of the plants with sowings made after the optimum date was established in all experiments and this confirmed the conclusions from the earlier experiments. There was also seasonal variation in the extent to which wide spacings, with earlier-sown cotton, were able to compensate for the fewer plants per unit area.

The variation in response to manuring with sowing-date was not clearly defined owing, apparently, to interference by disease-damage. Where disease-damage was light the greater response to manuring with earlier sowing, established at the Research Farm, was once more obtained.

An additional experiment, designed to augment the available information on different numbers of plants per hole and different dates of thinning, is also discussed. The experiment comprised 240 plots and, in addition to showing that good yields could be obtained with late sowings if less drastic thinning were employed, demonstrated the varying importance of date of thinning as a factor controlling yield.

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THE SOILS OF SCOTLAND

Pt. III. THE CENTRAL VALLEY AND SOUTHERN UPLANDS

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THE central or midland valley consists of a tectonic trough about 50 miles wide stretching in a north-easterly and south-westerly direction from coast to coast. It is defined sharply on the north from the Highlands and less sharply on the south from the Southern Uplands by two series of faults. Only in a general sense is it a valley, for within it there are several ranges of hills. Along the northern boundary there is a broad valley, then a line of volcanic hills, then a wide lowland stretch, and to the south of this another rather discontinuous line of hills with an ill-defined valley separating it from the Southern Uplands. These hills consist of lavas, intrusive dykes, sills, and plugs, and some of them have an altitude of 1,500–2,000 ft. (457–610 m.). In his agricultural atlas of Scotland, Wood recognizes an East-Central and a West-Central region, the former comprising a belt along the east coast.

The Southern Uplands lie between the Central Valley and the English border, and consist of a great tableland stretching across the south of Scotland—the denuded remains of an old mountain range. The relief is much gentler than in the Highland region; the hills are rounded or flattish on the tops and rarely exceed 2,000 ft. (610 m.) in height. Much of the high ground consists of moorland used for sheep-grazing. The Tweed basin and the south-western coastal belt are different from the rest of the area and in Wood's atlas these are dealt with as separate agricultural regions.

Climate.—The western part of the Central Valley has on the whole a much higher rainfall than the eastern. A belt along the east coast has a rainfall of less than 30 in. (762 mm.), whilst on the west there is a rainfall of 35–60 in. (889–1,524 mm.) and over 60 in. in places. The west is characterized by cooler and wetter summers and by less sunshine than the east. The same is true of the Southern Uplands region, and associated with this climatic difference the moors in the west are found much nearer to sea-level than in the east.

Geology.—The Central Valley consists largely of sedimentary rocks, but there are considerable areas of igneous materials—lavas, dykes, &c. The two main sedimentary formations are Carboniferous and Old Red Sandstone and, as would be expected from the range of materials found in these formations (conglomerates, marls, limestones, grits, sandstones, shales, coals, and iron-stones), they give rise to a number of widely different soils. In the Old Red Sandstone formation calcareous materials occur in the marls, and in the Carboniferous they occur in the form of limestones and limy shales.

The igneous rocks vary from highly basic to acid and form the hilly ground of the region.

There are extensive alluvial deposits in the valleys of the Rivers

Tay, Forth, and Clyde forming carse lands, and throughout the Central Valley there are tracts of peat which were more extensive in former times.

The Southern Uplands consist of highly folded sediments mainly of Ordovician and Silurian age, but on the lower ground to the south Carboniferous, Old Red, and New Red Sandstone formations are found. There are also granitic intrusions. In the Ordovician and Silurian formations, which cover most of the area, the rocks are mainly shales, hard grits, and greywackes, which are very resistant to weathering, and a group of basic and intermediate lavas. Most of the region is covered with glacial drift, but on the higher ground this is thin or absent and there are extensive tracts of hill peat.

Agriculture and forestry.—Agriculturally there is a marked difference between the eastern and western portions of the Central Valley, and this difference is due chiefly to climate. In the east the farming is predominantly arable, especially near the coast and below 600 ft. (182 m.), and in the west, where there is a higher rainfall and less sunshine, pastoral farming is the general rule.

The coastal portion of the Lothians below 500 ft. (152 m.) may be taken as an example of the most intensively farmed land in Scotland, and a typical rotation in East Lothian is (1) wheat, (2) turnips, (3) barley, (4) hay, (5) oats, (6) potatoes.

In the west, barley practically disappears and in most parts there is relatively little wheat; on the other hand, the area under permanent and rotation grass is very much greater in the west than in the east. Associated with these climatic and cropping differences the proportion of cattle, and especially dairy cattle, is greater in the west, and the great development of dairying in the west is also due to the very large population in Glasgow and the surrounding districts. The upper limit of arable farming is much higher in the east than in the west; oats are found here and there in the Lothians at an altitude of well over 1,000 ft. (305 m.) and wheat as high as 700 ft. (213 m.), but most of the wheat is grown below 500 ft. (152 m.). Early potatoes are grown chiefly in the south-west coastal districts and to a less extent in the coastal belt of the Lothians—usually on raised beaches. There is a good deal of market-gardening, especially in the Clyde Valley and the Lothians, and in one or two districts (especially Blairgowrie) raspberry-growing is important.

The percentage of the total area which is under timber is much lower in this region than in the north-eastern region, and the proportion of hardwoods compared with conifers is higher—particularly in Midlothian and West Lothian. Much of the land which was originally under forest has been cleared for agricultural purposes, and destruction of the forests occurred in the past through wars and fires. A great deal of timber was used for iron-smelting and other industrial purposes, with the result that in the sixteenth century the southern part of Scotland was largely denuded of its forest, and much of the present woodland has been planted for amenity reasons.

In the Southern Uplands the higher ground is moorland, used for sheep-grazing, and the density of sheep is much lower in the west than

in the drier east. On the lower ground, e.g. the Tweed Valley, there is arable farming, but most of the region is essentially sheep-grazing land. Probably much of this area was at one time well wooded but, as in the Central Valley, great destruction of the forest occurred in the past.

Soils.—The soils of the Central Valley have been studied by various workers. The reaction, exchangeable calcium, and 'lime-requirement' of soils in the south-east were investigated by Ogg and Dow,[1] and the exchangeable bases by Smith.[2] It was found that the majority of the cultivated soils examined had a pH between 5 and 6·5, but the soils in areas where the underlying rock was Carboniferous limestone were less acid and in many cases were alkaline. A detailed acidity survey of two parishes in the east of Scotland was carried out by Ogg and Dow,[3] and in the west of Scotland by Louden.[4] Marked differences were found and the need for liming in certain areas was emphasized.

In a number of soils Smith and I. M. Robertson[5] studied the influence of the plant upon seasonal changes in soil acidity, and Smith and A. Robertson[6] investigated the effect of lime and sulphur on soil acidity, crop yield, and the absorption of calcium and sulphur by the plant.

The availability of the potassium in a group of soils from the south-east of Scotland was studied by various methods by R. Stewart.[7] Ultimate analyses showed that most of the soils contained large reserves of potash, but from Neubauer seedling-analyses he concluded that there was a deficiency of available potash in most of the samples. Smith and Coull,[8] and Smith and Dryburgh[9] studied the technique of the *Aspergillus niger* method of estimating soil fertility, and applied the method to soils of the south-east of Scotland.

On the bacteriological side, studies have been carried out by Cunningham, Gibson, Khalil, and Selim. Cunningham and Jenkins[10] worked on *Bacillus amylobacter* with special reference to its life-cycle, and Cunningham[11] carried out experiments on the cultivation of lucerne in which he refers to soil conditions. Gibson studied the decomposition of urea[12] in a number of Scottish soils, and also investigated strains of the *Bacillus pasteuri* group,[13] isolated from soils and manures. Khalil[14] studied the effect of drying on the microbiological processes in soils, and Selim[15] carried out work on nitrogen-fixing bacteria. Extensive studies of the geology and mineralogy of soils in the south of Scotland have been made by Hart.[16] The mineral composition of typical soils has been described and the content of the fine-sand fractions discussed in detail. The soils were selected over the different geological formations of the area and were shown to possess a fairly high content of silicate

[1] *J. Agric. Sci.*, 1928, **18**, 131.
[2] Ibid. 1925, **15**, 466; 1928, **18**, 68.
[3] *Scot. J. Agric.*, 1928, **11**, 273.
[4] Ibid. 1929, **12**, 383.
[5] *J. Agric. Sci.*, 1931, **21**, 822.
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[10] *J. Agric. Sci.*, 1927, **17**, 109; *Proc. Int. Cong. Soil Sci., Washington*, 1927, **3**, 144.
[11] *Scot. J. Agric.*, 1928, **11**, 42.
[12] *J. Agric. Sci.*, 1930, **20**, 549; *Zentralbl. Bakt.*, 1930, **81**, 45.
[13] *J. Bact.*, 1934, **28**, 295; 1934, **28**, 313.
[14] *Zentralbl. Bakt.*, 1929, **79**, 93.
[15] Ibid. 1931, **83**, 311.
[16] *J. Agric. Sci.*, 1929, **19**, 90; 1929, **19**, 802.

materials, generally in a comparatively fresh state. The proportion of such minerals was highest in soils derived from igneous rocks and least in those found on sediments of Carboniferous age. Minerals bearing lime, potash, and phosphate were found to be present in variable amount, though the last-named were only noted infrequently. The soils can be grouped according to their mineral content—this grouping being found to depend on the geological history of the parent material. All the soils examined were formed on glacial drifts, and the results suggest that the local rocks have a preponderating influence on the composition of the matrix of the drift.

Preliminary field studies of soils on a geological basis were carried out by Monie,[1] who has also investigated draining problems in the Central Valley. An account of the soils of North Ayrshire has been published by the Staff of the Chemistry Department of the West of Scotland College of Agriculture,[2] and soil-texture maps of North and South Ayrshire have been prepared. The mechanical composition of the layers of a group of profiles in the east of Scotland was studied by Gracie.[3]

The five main soil groups found in the north-eastern region occur also in the Central Valley and Southern Uplands, but in the Central Valley there appears to be a higher proportion of brown soils than in other regions of Scotland. Many of the cultivated soils are on the border-line between slightly podsolized soils and brown soils, and some of these are probably podsolized soils altered by agricultural treatment; calcareous parent-materials are more common in the Central Valley than in the other regions.

In the Southern Uplands the Silurian and Ordovician formations are associated chiefly with podsolic, gley podsolic, gley and peat types.

(i) *Podsolic soils*.—Examples of podsolic soils are given from three localities in the Central Valley and one in the Southern Uplands.

1 (*a*). Podsolic soil over Lower Old Red Sandstone formation.

Profile 1 (Central Valley).

Location: Balmakewan, Marykirk, Angus.

Parent material: Boulder clay over Lower Old Red Sandstone formation.

Topography and elevation: Flat; 130 ft. (40 m.).

Rainfall and drainage: 30 in. (762 mm.); fairly good.

Vegetation: Old pine forest.

(1)	0–4 cm.	Litter of needles, leaves, &c.
(2)	4–5 cm.	Dark brown humus layer; roots abundant; greyish specks at bottom of layer.
(3)	5–8 cm.	Dark greyish-brown humus layer; spotted with white specks; roots abundant; no structure.

[1] *Scot. J. Agric.*, 1922, **5**, 126; 1923, **6**, 43; 1930, **13**, 51; 1933, **16**, 418.
[2] Memoirs of the Geol. Survey; Geology of North Ayrshire, 1929.
[3] *Proc. 1st Internat. Congress Soil Sci., Washington*, 1927, **1**, 378.

(4) 8–15 cm. Olive-grey brown silty loam; friable; small stones; speckled; roots present.

(5) 15–30 cm. Mottled ochre-yellow-brown and grey-brown silty loam; slightly more compact than (4); friable; few small stones; roots present.

(6) 30–70 cm. Reddish-brown light loam with patches of greyish-brown; compact; sandy; stones throughout; roots penetrate.

(7) 70–200 cm. Passes imperceptibly into dull brick-red layer of sandy drift; friable; few large stones; grey patches throughout from decaying sandstones.

TABLE 1. *Analyses of Podsolic Soil (over Lower Old Red Sandstone formation), Marykirk, Angus*

Layer	(1)	(3)	(4)	(5)	(6)	(7)
Depth (in cm.)	0–4	5–8	8–13	15–20	30–55	85+
pH	4·3	3·7	3·9	4·3	4·5	4·6
Loss on ignition %	90·7	85·0	11·6	8·6	2·7	1·9
Exchangeable Ca (m.eq.)	..	5·3	0·8	0·6	0·6	0·6
,, Mg ,,	..	0·1	..	..	..	..
,, H ,,	..	94·0	26·7	19·5	6·0	1·2
Clay %	..	..	8·9	10·1	5·5	3·8
Clay fraction SiO_2/R_2O_3	..	..	1·96	1·46	1·44	1·35
,, SiO_2/Fe_2O_3	..	..	12·62	8·10	5·90	5·36
,, SiO_2/Al_2O_3	..	..	2·32	1·79	1·91	1·80

Profile 2 (Central Valley).

Location: Gothens Farm, Blairgowrie, Perthshire.

Parent material: Glacial drift over Lower Old Red Sandstone formation (influenced also by Highland schists).

Topography and elevation: Flat to gentle slope; 200 ft. (61 m.).

Rainfall and drainage: About 30 in. (762 mm.); good.

Vegetation: Cultivated land (raspberries grown).

(1) 0–25 cm. Brown sandy loam; few stones; roots abundant and worm-holes common; rough crumb structure.

TABLE 2. *Analyses of Podsolic Soil (over Lower Old Red Sandstone formation), Blairgowrie, Perthshire*

Layer	(1)	(2)	(3)	(4)	(5)
Depth (in cm.)	0–25	25–45	45–60	75–90	100–120
pH	5·6	6·0	6·3	6·5	6·8
Loss on ignition %	7·1	2·6	2·5	2·4	2·2
Exchangeable Ca (m.eq.)	4·5	1·5	5·3	5·3	6·6
,, Mg ,,	0·5	0·3	1·1	1·9	2·2
,, H ,,	7·6	3·9	3·2	2·6	2·4
Clay %	9·9	4·7	14·9	20·2	19·1
Clay fraction SiO_2/R_2O_3	2·04	1·25	2·42	2·53	2·49
,, SiO_2/Fe_2O_3	9·88	3·80	10·57	10·50	9·89
,, SiO_2/Al_2O_3	2·57	1·87	3·15	3·33	3·33

(2) 25–45 cm. Lighter brown sandy loam with numerous rusty spots; somewhat cemented; dark brown to blackish concretions; streaks of surface soil; fewer roots and occasional worm-holes.

(3) 45–75 cm. Brown loam with tinges of rusty brown and grey; fairly compact; lower part of this layer heavier in texture.

(4) 75–90 cm. Reddish-brown heavy loam; few stones and slight mottling.

(5) 90 cm. + Similar to (4) but less mottling.

1 (*b*). Podsolic soil over Lower Carboniferous formation (Central Valley).

Location: Auchincruive, Ayrshire.
Parent material: Boulder clay over Coal Measures.
Topography and elevation: Gentle slope; 130 ft. (40 m.).
Rainfall and drainage: 36 in. (914 mm.); free.
Vegetation: Wooded pasture-land; chiefly species of *Festuca*, *Agrostis*, *Holcus*, and *Lolium*.

(1) 0–30 cm. Dark brown light sandy loam; few stones; many roots to depth of 25 cm.

(2) 30–60 cm. Brown light sandy loam; grittier and more compact than (1); roots and worm-channels cease at 45 cm.

(3) 60–90 cm. Fairly sharp transition to rusty brown compacted sandy loam, showing iron staining, and free from stones.

(4) 90–95 cm. Transition layer to yellowish-brown compacted fine sandy loam.

(5) 95–110 cm. Yellowish-brown compacted sandy loam, less gritty than (4); a few rounded and sub-angular stones present.

(6) 110–120 cm. Darkish brown gritty sandy loam; very much compacted; a few rounded and sub-angular stones.

(7) 120 cm. + Brown fine silty loam with purplish tinge; shaly material present; grey and dull orange mottling; few stones.

TABLE 3. *Analyses of Podsolic Soil (over Lower Carboniferous formation),* Auchincruive, Ayrshire*

Layer	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Depth (in cm.)	0–30	30–60	60–90	90–95	95–110	110–120	120+
pH	5·2	5·7	5·9	6·1	6·1	6·3	6·5
Loss on ignition %	7·3	4·3	3·6	4·0	3·2	2·8	4·8
Exchangeable Ca (m.eq.)	2·7	3·0	3·1	2·2	2·3	2·2	9·8
,, Mg ,,	<0·1	..	..	..	..	..	..
Clay %	10·6	7·1	4·8	7·5	6·2	5·4	20·4
Clay fraction SiO_2/R_2O_3	1·64	1·30	1·11	1·00	1·17	1·83	2·36
,, SiO_2/Fe_2O_3	6·04	4·52	3·21	2·22	2·72	7·42	9·10
,, SiO_2/Al_2O_3	2·26	1·82	1·70	1·83	2·08	2·42	3·19

* Data supplied by I. C. Jack.

1 (*c*). Podsolic soils over Silurian formation (Southern Uplands).

Profile 1.

Location: Wull Muir, Broad Law, Moorfoot Hills, Midlothian.
Parent material: Boulder clay over shale.
Topography and elevation: Gentle slope; 1,250 ft. (381 m.).
Rainfall and drainage: About 35–40 in. (889–1,016 mm.); fairly good.
Vegetation: *Eriophorum vaginatum*; *Callina vulgaris* and *Vaccinium Myrtillus* dominant; *Nardus stricta*; *Deschampsia flexuosa* and *Molinia coerulea* abundant.

(1) 0–5 cm. Mat of heather and blaeberry roots, slightly decomposed.
(2) 5–20 cm. Black peaty material; many roots and few stones; silty texture.
(3) 20–27 cm. Greyish-black peaty loam, containing much mineral material; gritty, with white specks; some fresh roots, but many decayed, with staining round them.
(4) 27–32 cm. Coffee-brown loam, colour probably due to staining with organic matter; friable and gritty; small stones throughout and no definite structure; roots present; slightly damp.
(5) 32–45 cm. Medium-brown loam, gritty and friable; slightly stony; roots present; no definite boundary between layers (4) and (5); damp.
(6) 45–80 cm. (Variable) Greyish-brown loam; gritty and friable; no definite structure; very stony and stones mostly angular; some brown staining; colour becomes more uniformly grey-brown with depth.
(7) 80 cm. + Rock rubble of broken shale with small admixture of fine material.

TABLE 4. *Analyses of Podsolic Soil (over Silurian formation), Wull Muir, Moorfoot Hills, Midlothian*
Profile 1

Layer	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Depth (in cm.)	0–5	5–20	20–27	27–32	32–45	45–80	135–150
pH	4·0	3·8	4·1	4·3	4·7	4·7	4·9
Loss on ignition %	92·3	41·0	17·5	15·4	12·0	4·5	5·9
Exchangeable Ca (m.eq.)	..	0·9	0·6	0·7	0·6	0·6	0·9
,, Mg ,,	..	0·7	0·2	0·2	0·1	0·1	0·5
,, H ,,	86·3	50·7	36·0	32·0	18·3	5·2	6·9
Clay fraction SiO_2/R_2O_3	..	..	2·80	1·81	1·21	1·65	1·60
,, SiO_2/Fe_2O_3	..	..	31·59	8·11	4·36	6·49	6·69
,, SiO_2/Al_2O_3	..	..	3·07	2·33	1·68	2·21	2·10

Profile 2.

The following is an example of a podsolic soil over Silurian shale in the same locality as the last but on a sloping gravelly bank:

Vegetation: *Agrostis canina*, *A. vulgaris*, *Festuca ovina*, *Galium*

saxatile; less abundant, *Potentilla sylvestris*, *Luzula campestris*, *Nardus stricta*.

(1) 0–6 cm. Mat of grass roots.

(2) 6–17 cm. Light chocolate-brown friable loam with many grass roots; few stones; slightly powdery when dry; ochre yellow spots; worm-holes.

(3) 17–40 cm. Bright brown friable silty loam; slightly gritty; some stones; damp; roots common; pores and worm-holes; no definite structure.

(4) 40–70 cm. Grey-brown very pebbly and gritty silty loam; cemented; much silty material amongst interstices of shale pebbles; slightly damp; brown patches; roots present.

(5) 70 cm. + Shaly rubble, mostly angular and flat; silty interstitial material; very hard and appears to be cemented; damp; roots penetrate into this layer.

TABLE 5. *Analyses of Podsolic Soil (over Silurian formation), Wull Muir, Moorfoot Hills*
Profile 2

Layer	(1)	(2)	(3)	(4)	(5^1)	(5^2)
Depth (in cm.)	0–6	6–17	17–40	40–70	70–90	90+
pH	4·5	4·4	4·6	4·7	4·9	5·2
Loss on ignition %	52·3	16·5	11·3	7·5	4·6	4·3
Exchangeable Ca (m.eq.)	2·2	0·7	0·6	0·6	0·6	4·6
,, Mg ,,	2·6	0·8	0·6	0·4	0·6	2·3
,, H ,,	39·7	23·8	18·1	13·7	8·1	5·2
Clay fraction SiO_2/R_2O_3	..	1·91	1·67	1·56	2·03	2·38
,, SiO_2/Fe_2O_3	..	8·63	7·40	6·34	9·83	11·54
,, SiO_2/Al_2O_3	..	2·45	2·16	2·08	2·56	2·91

The above examples illustrate podsolic soils on three geological formations and under five different types of vegetation. The parent materials are light in texture, allowing free drainage, and the podsolic type is usual under these conditions. The clay-fraction analyses show translocation of sesquioxides and there are also morphological evidences of podsolization. In the Blairgowrie profile, where the texture becomes heavier with increasing depth, there is some evidence of slight gleying in the C horizon.

(ii) *Gley podsolic soils*.—Examples are given over Carboniferous and Silurian formations and also over trachyte.

2 (*a*). Gley podsolic soils over the Calciferous Sandstone Series of the Carboniferous formation (Central Valley).

Two profiles are described, one in Moffat Wood and the other in adjoining cultivated ground on the farm of Spittalrig.

Uncultivated profile.

Location: Moffat Wood, Gladsmuir, East Lothian.

Parent material: Boulder clay over the Calciferous Sandstone Series of the Lower Carboniferous.

Topography and elevation: Flat, 300 ft. (91 m.).
Rainfall and drainage: 28 in. (711 mm.); slightly impeded.
Vegetation: Chiefly pine forest.

(1) 0–5 cm. Surface litter of needles, leaves, &c.
(2) 5–10 cm. Brownish-grey silty loam; damp; structureless; roots present; stoneless; compact.
(3) 10–20 cm. Predominantly grey silty loam with brown streaks along root-channels; rusty brown spots and lighter grey flecks; minute pores; friable when dry; compact.
(4) 20–45 cm. Mottled grey and ochre-yellow silty clay; rusty brown spots around root-channels; friable; compact; stones rare; roots fairly abundant; pores; structureless.
(5) 45–90 cm. As in layer (4) but grey predominating; more stony; particles of coal and decaying sandstone.
(6) 90 cm.+ Reddish-brown slightly gritty clay with red, grey, and black specks; stones present; compact, but roots penetrate; sandy phase occurs in places.

TABLE 6. *Analyses of Gley Podsolic Soil (uncultivated) (over Lower Carboniferous formation), Moffat Wood, East Lothian*

Layer	(2)	(3[1])	(3[2])	(4)	(5)	(6)
Depth (in cm.)	5–7	10–15	15–20	20–35	50–60	100+
pH	4·0	3·9	4·0	4·3	4·5	5·4
Loss on ignition %	36·3	8·4	4·6	6·6	5·0	5·1
Exchangeable Ca (m.eq.)	4·0	0·9	0·6	1·0	1·0	6·8
,, Mg ,,	1·8	0·7	0·9	0·9	1·2	4·1
,, H ,,	41·2	19·3	11·1	10·0	7·9	3·5
Clay %	20·7	22·4	27·0	36·9	28·1	27·9
Clay fraction SiO_2/R_2O_3	2·26	2·29	2·20	1·82	1·77	2·26
,, SiO_2/Fe_2O_3	19·67	50·48	28·44	6·23	6·61	11·71
,, SiO_2/Al_2O_3	2·55	2·39	2·39	2·57	2·42	2·80

Cultivated profile at Spittalrig Farm.

(1) 0–25 cm. Dark chocolate-brown heavy loam; gritty and pebbly; rough crumb structure; cracks in very dry weather; full of roots; worm-holes; stones frequent.
(2) 25–40 cm. Ochre and grey loam; gritty; compact; structureless; stony; roots penetrate; the ochre-and-grey colour due in part to decaying yellow and white sandstone.
(3) 40–65 cm. (Variable.) Brown and grey clay; gritty, sticky, and damp; much rusty mottling; some yellow coloration due to sandstone; black particles of coal and shale; roots penetrate.
(4) 65–150 cm. Similar to above but with more intense grey patches and streaks; mottled brown and grey; stony; roots penetrate to 120 cm.

(5) 150 cm.+ Chocolate-brown boulder clay; stiff and sticky; damp; slight rusty and grey mottling at 150 cm.; stones are white, yellow, and purple sandstones, coal, shale, limestone, and basalt.

TABLE 7. *Analyses of Gley Podsolic Soil (cultivated) (over Lower Carboniferous formation), Spittalrig, East Lothian*

Layer	(1)	(2)	(3)	(4^1)	(4^2)	(5)
Depth (in cm.)	0–25	25–40	40–65	65–100	100–140	150+
pH	6·2	7·2	7·0	5·4	5·3	5·3
Loss on ignition %	8·0	4·8	5·7	6·1	6·0	6·6
Exchangeable Ca (m.eq.)	10·0	6·8	7·5	5·2	3·7	4·6
,, Mg ,,	1·0	1·1	1·8	2·9	3·0	3·5
,, H ,,	0·9	0·2	0·6	2·2	3·4	2·6
Clay %	20·0	23·6	29·3	28·0	28·2	28·0
Clay fraction SiO_2/R_2O_3	1·54	1·63	1·78	1·89	2·19	2·02
,, SiO_2/Fe_2O_3	9·76	5·15	6·42	7·67	12·27	9·30
,, SiO_2/Al_2O_3	1·82	2·37	2·47	2·50	2·58	2·57

2 (*b*). Peat gley podsolic soil over Silurian formation (Southern Uplands).

Location: Wull Muir, Moorfoot Hills, Midlothian.
Parent material: Boulder clay over Silurian shale.
Topography and elevation: Fairly steep slope; 1,250 ft. (381 m.).
Rainfall and drainage: About 35–40 in. (889–1,016 mm.); impeded.
Vegetation: *Nardus stricta* dominant; *Deschampsia flexuosa*, *Molinia coerulea*, *Agrostis canina*, *Festuca ovina*, *Galium saxatile*, and *Polytrichum commune* abundant.

(1) 0–15 cm. Black amorphous peat, full of roots; coarse lumpy structure.
(2) 15–25 cm. Dark grey stony heavy loam; structureless; wet.
(3) 25–25·5 cm. Dark brown and rusty hard-pan; roots penetrate in places.
(4) 26–55 cm. Fawny-brown stony heavy loam; structureless and not very compact; roots penetrate.
(5) 55–65 cm. Greenish-brown stony layer with interstitial finer material; structureless; roots penetrate.

TABLE 8. *Analyses of Peat Gley Podsolic Soil (over Silurian formation), Wull Muir, Moorfoot Hills*

Layer	(1)	(2)	(4^1)	(4^2)	(5)	(6)	(7^1)	(7^2)
Depth (in cm.)	0–15	15–25	25–35	45–55	55–65	65–75	80–90	150+
pH	4·3	4·3	4·8	5·1	4·8	4·9	4·8	5·0
Loss on ignition %	79·3	16·1	10·1	6·6	5·2	7·4	4·7	3·2
Exchangeable Ca (m.eq.)	1·8	0·8	0·5	0·5	0·5	0·6	0·5	0·5
,, Mg ,,	$<0·1$	..	..	..	..	..	..	..
,, H ,,	56·9	29·4	16·9	8·8	6·4	7·6	7·6	4·9
Clay %	..	22·6	21·1	13·9	10·1	8·5	12·5	8·7
Clay fraction SiO_2/R_2O_3	..	2·64	1·77	1·48	1·57	1·36	1·81	1·67
,, $SiO_2Fe_2O_3$	..	32·45	7·81	5·57	6·40	5·75	10·40	8·00
,, SiO_2/Al_2O_3	..	2·87	2·29	2·01	2·07	1·77	2·19	2·11

(6) 65–75 cm. Fawny-brown loam similar to layer (5), but redder in colour and fewer roots.

(7) 75 cm. + Brown loam with many small angular pieces of slate; greenish-grey in places; structureless; very few roots.

2 (*c*). Gley podsolic soil over trachyte (Central Valley).
Location: Smiddy park, Harperdean, Haddington.
Parent material: Boulder clay over trachyte.
Topography and elevation: Level; 500 ft. (152 m.).
Rainfall and drainage: About 25 in. (635 mm.); fairly good.
Vegetation: Pasture (in rotation).

(1) 0–25 cm. Dark brown heavy loam; powdery when dry; slightly gritty, but stones infrequent; worm-holes common; roots abundant.

(2) 25–50 cm. Yellow-brown heavy loam with greyish tint; some rusty and ochre mottling; rusty staining round root-channels; many pores; worm-channels and roots common; stones fairly frequent; lumpy indefinite structure.

(3) 50–75 cm. Brown clay loam with greyish tint; gritty and stony; rusty and grey mottling; worm-holes frequent; cloddy when broken up, and grey films on surfaces of lumps; more uniformly brown in colour with depth.

(4) 75–165 cm. Brown gritty and stony boulder clay; rusty and grey mottling; stones frequent; trachyte, basalt, yellow, and purple sandstones, coal, grits, and shale; stones generally soft and decayed.

TABLE 9. *Analyses of Gley Podsolic Soil (over trachyte), Harperdean, Haddington, West Lothian*

Layer	(1)	(2)	(3)	(4^1)	(4^2)	(4^3)
Depth (in cm.)	0–25	30–45	55–75	95–110	125–150	150–165
pH	6·6	7·4	7·8	7·2	6·5	7·4
Loss on ignition %	8·1	5·1	5·1	4·8	5·9	5·0
Exchangeable Ca (m.eq.)	11·8	11·3	12·1	13·2	10·7	22·2
" Mg "	1·1	0·9	1·3	1·3	1·5	5·0
Clay %	23·9	28·5	28·8	26·2	27·0	14·2
Clay fraction SiO_2/R_2O_3	1·89	1·70	2·08	2·12	2·13	2·66
" SiO_2/Fe_2O_3	11·62	7·72	12·11	13·51	14·58	9·72
" SiO_2/Al_2O_3	2·27	2·19	2·52	2·52	2·49	3·66

The above examples of gley podsolic soils are taken from three different types of parent material, and occur under three types of vegetation. The parent materials are heavier in texture than those described in the podsolic group, and this no doubt accounts for the gleying. The two profiles from cultivated land show evidence of marked alteration through treatment and have probably been heavily limed in the past. The parent material in the slightly podsolized Harperdean profile is

of very mixed origin, and is evidently influenced largely by the neighbouring Carboniferous formation. This soil is on the border-line of the brown-soil group, but the analyses show fairly marked translocation of sesquioxides.

(iii) *Gley soils.*—Two examples of a gley and a peat gley are given from Wull Muir, Moorfoot Hills. The parent material in both cases is boulder clay over Silurian shale; the height above sea-level is 1,250 ft. (381 m.), and the rainfall 35–40 in. (889–1,016 mm.).

Gley profile (Southern Uplands).

Vegetation: *Juncus communis* and *Carex Goodenovii* dominant; *Holcus lanatus*, *Trifolium repens*, and *Anthoxanthum odoratum* abundant.

(1) 0–5 cm. Mat of roots and moss.
(2) 5–15 cm. Brownish-grey silty loam; wet; no definite structure; few stones; roots common; some brown patches along root-channels.
(3) 15–22 cm. (Variable.) Grey silty loam with brown patches and streaks; wet; few stones; roots common; brown staining along root-channels.
(4) 22–35 cm. Brown silty loam with greyish tinge; wet; slightly gritty; few stones; much brown mottling and staining along root-channels.
(5) 35–55 cm. Greyish-brown silty loam with sandy patches; wet; stones common; blackish particles or concretions; roots penetrate; brown staining along root-channels.
(6) 55 cm.+ Stony silty loam; grey-brown with brown patches; very wet; gritty.

TABLE 10. *Analyses of Gley Soil (over Silurian shale), Wull Muir, Moorfoot Hills*

Layer	(1)	(2)	(3)	(4)	(5)	(6)
Depth (in cm.)	0–5	5–15	15–22	22–35	35–55	55+
pH	5·2	5·3	5·6	5·4	5·8	5·5
Loss on ignition %	18·4	12·6	7·3	5·2	4·1	3·6
Exchangeable Ca (m.eq.)	5·3	3·7	4·1	4·0	3·5	1·8
,, Mg ,,	2·0	1·4	1·3	1·4	1·6	0·7
,, H ,,	14·6	12·5	9·0	6·5	6·0	4·8
Clay fraction SiO_2/R_2O_3	2·44	2·32	2·37	2·28	2·12	1·82
,, SiO_2/Fe_2O_3	14·11	12·45	11·50	10·74	9·71	8·72
,, SiO_2/Al_2O_3	2·96	2·85	2·98	2·89	2·71	2·29

Peat Gley profile (Southern Uplands).

Vegetation: *Eriophorum vaginatum*, *Carex Goodenovii*, *Deschampsia flexuosa*, and *Festuca ovina*; spots of *Calluna vulgaris*.

(1) 0–4 cm. Mat of roots.
(2) 4–30 cm. Fibrous peaty material; roots abundant.
(3) 30–37 cm. Greyish silty loam with much organic staining; many plant roots with brown staining around them; most of roots decayed.

(4) 37–50 cm. Grey fine sandy loam; damp; many roots; some green patches; brown staining, especially along root-channels.

(5) 50–65 cm. Greenish-grey silt; gritty and slightly stony; damp; roots common—some decayed, with brown patches along channels.

(6) 65–95 cm. Greyish-brown gritty and stony silty loam; many greyish-green patches; becomes more uniform in colour with increasing depth; damp; roots penetrate only to top of layer.

(7) 95 cm. + Brown gritty and stony loam; clayey; wet; very stony—shattered shale; greyish-green patches, probably due to decayed shale.

TABLE 11. *Analyses of Peat Gley Soil (over Silurian shale), Wull Muir, Moorfoot Hills*

Layer	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Depth (in cm.)	0–4	4–30	30–37	37–50	50–65	65–95	150–165
pH	4·3	3·9	4·7	5·1	5·0	6·0	6·7
Loss on ignition %	91·0	70·2	9·4	1·2	3·2	3·7	4·0
Exchangeable Ca (m.eq.)	..	5·9	2·1	1·2	3·7	9·2	13·5
,, Mg ,,	..	2·9	1·3	0·8	2·1	4·1	4·6
,, H ,,	27·8	49·1	12·3	1·2	2·3	0·6	0·3
Clay fraction SiO_2/R_2O_3	..	..	2·44	2·35	2·38	2·41	2·31
,, SiO_2/Fe_2O_3	..	..	21·28	14·55	12·66	11·49	9·88
,, SiO_2/Al_2O_3	..	..	2·75	2·80	2·94	3·05	3·01

Both profiles described are from the Southern Uplands at a fairly high altitude. Compared with the podsolic and gley podsolic soils, already described from the same locality, they show a rather higher pH and a higher content of exchangeable calcium and magnesium. The SiO_2/Fe_2O_3 decreases in both profiles with increasing depth.

(iv) *Brown soils.*—In Part II of this paper, brown soils over gabbro were described. In the Central Valley and Southern Uplands, examples over dolerite and the Carboniferous and Old Red Sandstone formations are given.

4 (*a*). Brown soils over Lower Old Red Sandstone formation.

Profile 1 (Central Valley).

Location: Bent, Laurencekirk, Kincardineshire.

Parent material: Boulder clay over Lower Old Red Sandstone formation.

Topography and elevation: Flat to gently rolling; 230 ft. (70 m.).

Rainfall and drainage: 33 in. (838 mm.); good.

Vegetation: Cultivated ground.

(1) 0–25 cm. Greyish-brown gritty heavy loam; stony; when dry becomes lighter in colour and crumbly; worms present.

(2) 25–125 cm. Reddish-brown stony heavy loam; small soft black specks; occasional patches bright red in colour; fairly compact; few roots below 45 cm.

TABLE 12. *Analyses of Brown Soil (over Lower Old Red Sandstone formation), Laurencekirk, Kincardineshire*

Layer	(1[1])	(1[2])	(2[1])	(2[2])	(2[3])	(2[4])
Depth (in cm.)	0–12	12–25	25–35	35–45	65–75	115–25
pH	6·3	6·4	5·8	5·4	5·6	5·9
Loss on ignition %	6·2	6·5	3·9	3·2	2·8	3·2
Exchangeable Ca (m.eq.)	10·6	9·9	6·3	5·5	6·0	8·4
,, Mg ,,	2·0	1·5	2·0	2·9	4·2	4·2
,, H ,,	1·8	2·8	2·8	2·1	2·1	1·4
Clay %	18·9	19·5	20·4	20·5	20·2	21·8
Clay fraction SiO_2/R_2O_3	2·68	2·68	2·83	2·49	2·64	2·74
,, SiO_2/Fe_2O_3	13·76	15·99	15·15	13·45	13·79	14·17
,, SiO_2/Al_2O_3	3·32	3·22	3·48	3·05	3·27	3·40

Profile 2 (Central Valley).

Location: Balfeith, Fordoun, Kincardineshire.

Parent material: Boulder clay over marls of Lower Old Red Sandstone formation.

Topography and elevation: Level; 200 ft. (61 m.).

Rainfall and drainage: 33 in. (838 mm.); fairly good.

Vegetation: Pasture (in rotation).

(1) 0–25 cm. Light reddish-brown heavy loam; many roots; occasional stones; tendency to crumb structure.

(2) 25–35 cm. Reddish-brown stony heavy loam; few roots; structureless.

(3) 35–80 cm. Bright reddish-brown stony loam; compact; no roots; structureless.

(4) 80–90 cm. Reddish-brown rotten marl with some fine material in cracks.

(5) 90–100 cm. Rotten rock with less fine material than (4); wet.

TABLE 13. *Analyses of Brown Soil (over Lower Old Red Sandstone marl), Fordoun, Kincardineshire*

Layer	(1[1])	(1[2])	(2)	(3[1])	(3[2])	(4)
Depth (in cm.)	0–12	12–25	25–35	45–55	70–80	80–90
pH	6·3	6·7	6·9	7·2	7·1	7·1
Loss on ignition %	7·0	6·0	3·8	3·4	3·8	4·0
Exchangeable Ca (m.eq.)	12·5	14·2	12·8	12·9	11·7	11·6
,, Mg ,,	2·5	3·0	3·6	4·8	4·5	4·9
,, H ,,	5·3	1·9	1·6	2·0	0·4	2·2
Clay %	24·3	23·6	18·2	16·4	17·9	17·9
Clay fraction SiO_2/R_2O_3	2·81	2·69	3·03	2·85	3·03	3·05
,, SiO_2/Fe_2O_3	13·14	11·09	15·95	12·68	20·50	16·58
,, SiO_2/Al_2O_3	3·58	3·53	3·74	3·77	3·55	3·73

Profile 3 (Southern Uplands).

Location: Wallace Field, Bemersyde West End, Bemersyde, Berwickshire.

Parent material: Boulder clay over sandstone of Old Red Sandstone formation.

Topography and elevation: Gentle slope; 500 ft. (152 m.).

Rainfall and drainage: About 28 in. (711 mm.), free.

Vegetation: Grass (in rotation).

(1)	0–20 cm.	Brownish-red heavy loam; comparatively free of stones.
(2)	20–35 cm.	Similar to above, but very stony.
(3)	35–47 cm.	Brownish-red loam but lighter in colour than (1); stony.
(4)	47–65 cm.	Redder in colour than (3); texture similar; roots still present.
(5)	65–100 cm.	Reddish stony loam similar to layers (3) and (4); worms present.
(6)	100–35 cm.	Reddish loam similar in texture to above but deeper in colour.
(7)	135 cm. +	Shattered sandstone rock at variable depth.

TABLE 14. *Analyses of Brown Soil (over Old Red Sandstone formation), Bemersyde, Berwickshire*

Layer	(1)	(2)	(3)	(4)	(5)	(6)
Depth (in cm.)	0–20	25–35	37–47	55–65	80–100	115–135
pH	5·9	6·2	6·1	6·2	6·0	5·3
Loss on ignition %	5·4	3·8	3·6	2·9	2·7	2·9
Exchangeable Ca (m.eq.)	7·7	5·3	5·6	3·6	4·8	2·6
,, Mg ,,	1·0	0·6	0·8	0·7	1·3	1·7
,, H ,,	2·0	0·9	0·5	1·4	1·2	1·2
Clay %	20·5	19·0	19·9	17·9	18·8	21·7
Clay fraction SiO_2/R_2O_3	2·34	2·34	2·45	2·38	2·52	2·64
,, SiO_2/Fe_2O_3	12·82	11·54	12·51	9·01	10·63	9·32
,, SiO_2/Al_2O_3	2·87	2·94	3·02	3·24	3·31	3·35

4 (*b*). Brown soils over Carboniferous formation (Central Valley).

Profile 1.

Location: Clack O' Ford field, Oxwell Mains, Dunbar, East Lothian.

Parent material: Glacial drift over Carboniferous Limestone Series (influenced by adjoining Old Red Sandstone formation).

Topography and elevation: Level; 80 ft. (24 m.).

Rainfall and drainage: 24 in. (610 mm.), good.

Vegetation: Under cultivation.

(1)	0–30 cm.	Reddish-brown stony loam; free and friable; soft crumb structure.
(2)	30–110 cm.	Reddish-brown very stony loam; loose and structureless; roots penetrate to 100 cm.

TABLE 15. *Analyses of Brown Soil (over Carboniferous formation), Dunbar, East Lothian*

Layer	(1^1)	(1^2)	(2^1)	(2^2)	(2^3)
Depth (in cm.)	0–15	15–30	30–45	45–60	100+
pH	7·6	7·3	7·6	7·5	7·1
Loss on ignition %	6·2	4·8	3·8	3·7	3·4
Exchangeable Ca (m.eq.)	23·1	20·4	12·3	7·9	8·1
,, Mg ,,	1·9	2·0	1·3	0·7	0·8
Clay %	16·7	17·0	16·7	11·9	12·2
Clay fraction SiO_2/R_2O_3	2·05	2·01	2·03	2·04	1·96
,, SiO_2/Fe_2O_3	8·88	9·17	8·62	8·26	6·97
,, SiO_2/Al_2O_3	2·68	2·58	2·66	2·72	2·56

Profile 2 (Central Valley).

Location: Fox farm field, East Saltoun, East Lothian.
Parent material: Boulder clay over Carboniferous Limestone Series.
Topography and elevation: Level; 500 ft. (152 m.).
Rainfall and drainage: About 28 in. (711 mm.); fair.
Vegetation: Pasture (in rotation).

(1) 0–35 cm. Brown heavy loam; few stones; becomes slightly lighter in colour below 25 cm.

(2) 35–50 cm. Grey and yellow clay loam; compact; stones present.

(3) 50–110 cm. (Variable.) Grey, red, and orange mottled sandy clay; very compact; stones present; roots and worms in upper part of this layer.

(4) 110–130 cm. Yellow and red sandy clay overlying rock at about 150 cm.

TABLE 16. *Analyses of Brown Soil (over Carboniferous Limestone Series), East Saltoun, East Lothian*

Layer	(1^1)	(1^2)	(2)	(3^1)	(3^2)	(4)
Depth (in cm.)	0–23	25–35	40–50	55–70	75–95	115–130
pH	7·8	7·7	7·6	7·7	7·3	7·9
Loss on ignition %	8·5	7·1	6·7	7·2	7·0	12·8
Clay %	22·3	28·1	35·2	43·0	39·8	41·1
Clay fraction SiO_2/R_2O_3	1·98	1·88	1·81	1·80	2·00	1·56
,, SiO_2/Fe_2O_3	18·35	16·73	17·11	17·34	25·50	26·25
,, SiO_2/Al_2O_3	2·22	2·12	2·02	2·01	2·17	2·08

4 (*c*). Brown soil over dolerite (Central Valley).

Location: Peel Hill, Auchincruive, Ayrshire.
Parent material: Boulder clay over teschenitic dolerite sills.
Topography and elevation: Gentle slope; 100 ft. (30 m.).
Rainfall and drainage: About 36 in. (914 mm.); good.
Vegetation: Old pasture formerly cultivated; species of *Agrostis*, *Festuca*, and mosses dominant.

(1) 0–10 cm. Darkish chocolate-brown light loam; surface mat of grass and roots; free from stones.
(2) 10–27 cm. Light loam; lighter in colour than (1); gravel and small angular and rounded stones; roots not abundant below this layer.
(3) 27–35 cm. Similar to (2) but few roots; somewhat compacted.
(4) 35–45 cm. Light-brown sandy loam; some reddish-brown and black staining; compacted and free from stones and gravel; no trace of worms below this layer.
(5) 45–85 cm. Dark purplish-brown compact boulder clay; considerable admixture of shaly material; angular, sub-angular, and rounded stones present; irregular columnar structure in layers (2) to (5); roots stop at 55 cm.

TABLE 17. *Analyses of Brown Soil (over Dolerite),* Peel Hill, Auchincruive, Ayrshire*

Layer	(1)	(2)	(3)	(4)	(5)
Depth (in cm.)	0–10	10–27	27–35	35–45	45–85
pH	5·6	5·7	6·6	6·6	7·4
Loss on ignition %	10·5	6·6	3·9	3·0	4·0
Exchangeable Ca (m.eq.)	4·5	4·7	6·0	4·5	6·4
,, Mg ,,	<0·1	. .	. .	. .	. .
Clay %	12·6	12·1	14·7	6·0	11·0
Clay fraction SiO_2/R_2O_3	1·96	2·00	2·10	2·01	2·30
,, SiO_2/Fe_2O_3	6·70	7·21	7·55	8·70	8·84
,, SiO_2/Al_2O_3	2·77	2·69	2·90	2·70	3·10

* Data supplied by I. C. Jack.

As in the north-eastern region, the brown soils appear to be typically associated with parent material from basic rocks. The two profiles with the lowest pH in the parent material (Bent and Bemersyde) show evidence of having been limed in the past, and that from Bemersyde may be a regraded podsol. Translocation of sesquioxides, where it occurs, is slight and morphologically there is no evidence of podsolization. The analytical data for the Oxwell Mains, Harperdean, and East Saltoun profiles were supplied by R. L. Mitchell.

(v) *Soil with undeveloped profile* (Southern Uplands).

Location: Wull Muir, Moorfoot Hills.
Parent material: Drift over Silurian shale.
Topography and elevation: Slope, 1,250 ft. (381 m.).
Rainfall and drainage: About 35–40 in. (889–1,016 mm.); fairly good.
Vegetation: *Agrostis vulgaris*, *A. canina*, and *Festuca ovina* dominant; *Deschampsia caespitosa* abundant.

(1) 0–30 cm. Greyish-brown crumbly loam with thick root-mat on surface; occasional worms; stony; moist.
(2) 30–60 cm. Fawny-brown loam; gritty and sticky; few roots; stony; spots of lighter coloured material; greenish rotten rock; no roots below 60 cm.

(3) 60 cm.+ Fawny-brown loam; gritty and very stony; rusty brown spots; moist.

TABLE 18. *Analyses of Soil with undeveloped Profile (over Silurian shale), Moorfoot Hills*

Layer	(1^1)	(1^2)	(2^1)	(2^2)	(3^1)	(3^2)
Depth (in cm.)	0–10	10–20	30–40	50–60	60–70	150+
pH	5·2	5·6	5·9	6·1	6·2	6·1
Loss on ignition %	13·2	11·1	7·1	6·1	4·1	3·7
Exchangeable Ca (m.eq.)	4·7	5·6	5·6	5·3	4·9	7·0
,, Mg ,,	2·0	1·9	1·9	1·6	1·7	2·3
,, H ,,	15·0	11·7	8·5	8·0	5·3	4·1
Clay fraction SiO_2/R_2O_3	2·36	2·34	2·18	2·14	2·06	2·16
,, SiO_2/Fe_2O_3	11·87	11·81	10·10	9·82	8·88	10·07
,, SiO_2/Al_2O_3	2·95	2·92	2·77	2·73	2·68	2·76

The undeveloped state of the above profile is probably mainly due to percolation of water down the slope within the profile and partly to downwash of material. The pH and the contents of exchangeable calcium and magnesium are much higher than in the podsolic soils from the same locality.

Summary

A review has been given of previous soil investigations in Scotland. Typical soil profiles from various parts of the country have been described, and examples given from a wide range of parent materials. Determinations have been made of pH, loss on ignition, exchangeable calcium, magnesium and hydrogen, percentage of clay, and composition of the clay fractions.

The following broad groups are recognized: podsolic soils, gley podsolic soils, gley soils and deep peat, brown soils, and soils with undeveloped profiles. Further subdivisions are made on a geological basis.

Most of the Scottish soils examined come within the podsolic and gley podsolic groups; a peat-covering is common, especially in the Highlands and Hebrides. Brown soils which appear to be similar to the 'brown earths' of certain continental workers are not uncommon in the Central Valley and in parts of the north-eastern region.

Marked changes have been brought about in many soils through cultivation and treatment, and some of these cultivated soils, although originally podsolic, now resemble the brown soils.

Lysimeter experiments on a granitic drift soil in Aberdeenshire have been described, and a brief account given of fertility investigations and mineralogical studies.

I desire to acknowledge the valuable assistance I have received from Mr. H. G. M. Hardie, and also to thank various other members of the staff of the Macaulay Institute—in particular Dr. Hart and Dr. Muir—for much helpful criticism.

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THE EFFECTS OF VARYING AMOUNTS OF ANIMAL PROTEIN FED TO WHITE LEGHORN PULLETS

Pt. II. FACTORS CORRELATED WITH EGG-SIZE AND NUMBER OF EGGS

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THE data of the experiment presented in Part I of this paper (this *Journal*, 1935, 3, 215) provided an excellent opportunity to gather further evidence of the correlation between various characteristics of a pullet and the eggs she lays. The results have been obtained under Western Cape Province conditions, which differ not only from conditions existing in other parts of South Africa, but also from conditions in countries where similar experiments have been performed. (The material and methods utilized in obtaining these results are detailed in Part I.)

Review of literature.—That the weight of the eggs produced by a pullet gradually increases until a maximum is reached either in the first year of production or later, has long been established.

Maximum body-weight has been found significantly correlated with average annual egg-weight by Atwood [1], Atwood and Clarke [2], Jull [3], and Parkhurst [4].

No significant relationship was found between annual egg-production and the mean annual egg-weight by Hadley and Caldwell [5], Atwood [6], Atwood and Clarke [2], Jull [3], or Parkhurst [4].

Thompson [7] examined the records of 3,937 White Leghorn pullets for correlation between winter and annual production. He regarded the large number of records as a fair cross-section of the possible universe, and later also derived a series of regression equations for prediction purposes. A review of existing literature on short-term recording in relation to full-year recording is given by Thompson and need not be repeated here.

Short-time recording during a certain period of the year when the weight of egg laid approximates to the average annual weight has recently received attention. Jull [8] proposed the weighing of the first ten eggs of March and observed that, although this figure was applicable to a group of birds, it was unreliable when applied to individual birds. Of the 40 birds included in the experiment, 19 did not lay during every month of the eleven for which the experiment lasted, and were therefore not considered.

Maw and Maw [9] concluded from the results from 74 single-comb White Leghorns that the weighing of the first ten eggs laid in the fifth month gives a reliable estimate of the average annual egg-weight.

General.—It is fully recognized by the writers that the number of birds in the three groups was too small to obtain results sufficiently reliable for general application. In so far as the correlation coefficients here presented are in agreement with those obtained by other workers

using a very much larger number of birds, the significance of the results is rather enhanced, as they then hold good even when a small number of birds of comparatively large variability of weight and production is considered. On the other hand, where results are obtained that differ from those of workers who used a larger number of less variable birds, little significance can as yet be attached to them.

TABLE 1. *Correlation Coefficients (r) of Various Characteristics of Pullets*

Factors correlated	*Group I*	*Group II*	*Group III*
1. Number of eggs per annum and average annual weight of eggs per bird	$-0{\cdot}198\pm0{\cdot}23$	$-0{\cdot}118\pm0{\cdot}24$	$0{\cdot}26\pm0{\cdot}23$
2. Maximum body-weight and average annual weight of eggs per bird	$0{\cdot}263\pm0{\cdot}22$	$0{\cdot}534\pm0{\cdot}17$	$0{\cdot}462\pm0{\cdot}19$
3. Average body-weight and average annual weight of eggs per bird	$0{\cdot}306\pm0{\cdot}21$	$0{\cdot}435\pm0{\cdot}20$	$0{\cdot}338\pm0{\cdot}21$
4. Average monthly body-weight and average monthly weight of eggs per group	$0{\cdot}939\pm0{\cdot}028$	$0{\cdot}942\pm0{\cdot}029$	$0{\cdot}939\pm0{\cdot}029$
5. Winter production and annual production per bird	$0{\cdot}803\pm0{\cdot}085$	$0{\cdot}824\pm0{\cdot}078$	$0{\cdot}700\pm0{\cdot}12$
6. Average weight of winter-produced eggs and average annual weight of eggs per bird	$0{\cdot}667\pm0{\cdot}127$	$0{\cdot}608\pm0{\cdot}158$	$0{\cdot}603\pm0{\cdot}150$
7. Number of days of winter gap[1] and annual production per bird	$-0{\cdot}687\pm0{\cdot}12$	$-0{\cdot}522\pm0{\cdot}18$	$-0{\cdot}712\pm0{\cdot}12$
8. Difference in weight of last ten eggs before winter gap and first ten eggs after winter gap and number of days of winter gap	$0{\cdot}770\pm0{\cdot}096$	$0{\cdot}781\pm0{\cdot}097$	$0{\cdot}834\pm0{\cdot}076$

[1] 'Winter gap' as applied here denotes the number of days reckoned from the last egg laid by the pullet before she goes into a partial moult up to the first egg laid after the moult.

Correlation between Number of Eggs per annum and the Average Annual Weight of Eggs

Table 1 shows that the coefficient of correlation between annual numerical production and average annual egg-weight is $-0{\cdot}198\pm0{\cdot}23$, $-0{\cdot}118\pm0{\cdot}24$, and $+0{\cdot}26\pm0{\cdot}23$ for Groups I, II, and III respectively. Again the standard error has been used, and it is evident that there is no significant correlation between the above physical factors. The non-significance of the correlation is in accordance with the results of most workers. It is of interest that Groups I and II show a negative correlation, whilst Group III (high protein) shows a positive correlation. A measure of non-linear correlation was not calculated because of paucity of numbers.

Correlations between Body-weight and Size of Egg

1. *Maximum body-weight and average annual weight of eggs per bird.*—The maximum body-weight was taken as the highest weight the individual bird reached when monthly weights alone were taken during the thirteen months duration of the experiment. The correlation coefficients for Groups I, II, and III are $+0{\cdot}263 \pm 0{\cdot}22$, $+0{\cdot}534 \pm 0{\cdot}17$, and $+0{\cdot}462 \pm 0{\cdot}19$ respectively.

Again inconsistent results are obtained. Although all correlations are positive, only Groups II and III show significant correlations. Group I's correlation is not significant. As the maximum body-weight is reached by most birds during the period when production is at its heaviest, it is quite conceivable that with the heavy drain of protein for egg-production the low protein-content of the mash provided insufficient protein for normal increase of body-weight. Part I of this paper shows that the weight of egg was not influenced by the varying amounts of protein ingested. Hence the non-significance of the correlation for Group I can perhaps be attributed to the fact that at the height of production there was an adverse nutritive balance of the diet, and the birds could not ingest sufficient protein for increase of body-weight to a normal maximum and also for production.

2. *Average body-weight and average annual weight of eggs per bird.*—Groups I, II, and III have correlation coefficients of $+0{\cdot}306 \pm 0{\cdot}21$, $+0{\cdot}435 \pm 0{\cdot}20$, and $+0{\cdot}338 \pm 0{\cdot}21$ respectively.

The relative positions of the coefficients are the same as when the maximum body-weight is correlated with the average annual egg-weight. A higher coefficient is obtained in Group I, but is still not significant. The coefficient for Group II is lower but still significant, whilst in Group III it has fallen below significance. This would show that although both maximum and average body-weight show positive correlations with average annual egg-weight, they differ as measures of body-weight in their relationship with average annual egg-weight.

3. *Average monthly body-weight and average monthly egg-weight per group.*—Very high coefficients of correlation are found between the average body-weight for each month and the average weight of eggs for the same month, viz. $+0{\cdot}939 \pm 0{\cdot}028$, $+0{\cdot}942 \pm 0{\cdot}029$, and $+0{\cdot}939 \pm 0{\cdot}029$ for the three groups respectively.

This is to be expected, for, as previously shown (Pt. I, p. 226), there is a marked relationship between monthly variations in body-weight and size of egg during the first year of production of a pullet.

Correlations between Winter and Annual Production

The season termed 'winter' does not comprise the true winter months, but March, April, May, and June. During these months production is at its lowest and most pullets go into a partial moult.

1. *Winter production and annual production.*—The correlation between these two factors is very high and significant, being $0{\cdot}803 \pm 0{\cdot}085$, $0{\cdot}824 \pm 0{\cdot}078$, and $0{\cdot}700 \pm 0{\cdot}12$ for the respective groups.

These results are similar to those of most workers. Unfortunately,

owing to the pronounced influence of the wet winter months on the production of birds in the College Poultry Division and the small number of birds in each group, no attempt can be made at setting a numerical standard of winter-produced eggs to serve as a criterion for the annual production. The fact that the correlation coefficients are very high would indicate that a fairly accurate standard could be laid down.

2. *Average weight of winter-produced eggs and average annual weight of eggs per bird.* The correlation coefficients for the above factors are $0{\cdot}667 \pm 0{\cdot}127$, $0{\cdot}608 \pm 0{\cdot}158$, and $0{\cdot}603 \pm 0{\cdot}150$ for Groups I, II, and III respectively; the correlations being significant.

Here also the effect of the environmental and experimental conditions cannot be gauged; therefore no standard weight is suggested for winter-produced eggs as a criterion of annual production.

The recording of all pullets through the year is a task demanding more time and labour than the average poultry-breeder can afford. Many breeders in this country record only during the winter months. Comparatively, this is a much smaller task, for during these months egg-production is at its lowest. The fact that there are significant correlations between the number and size of eggs produced in winter and the number and size produced in the whole year would support the system of short-time recording, which, although not so accurate as yearly recording, would find more general application. Given sufficient data, standards for size and number of winter-produced eggs could be established to serve as a basis similar to the numerical-production table published by Thompson [7] for selection for breeding.

3. *Winter-gap period and annual production.*—For Groups I, II, and III the correlation coefficients are $-0{\cdot}687 \pm 0{\cdot}12$, $-0{\cdot}522 \pm 0{\cdot}18$, and $-0{\cdot}712 \pm 0{\cdot}12$. Most pullets in the College Poultry Division go through a partial winter moult, and these coefficients were calculated in order to decide which of the two factors, 'winter production' or 'winter gap' (cf. p. 314) would be the more reliable factor as a measure of annual production.

It will be noticed that these values of r are high and significant, but negative, showing that the shorter the moulting-period the higher the total annual production. Comparing these values with those obtained for winter production, we find the latter are higher and also more reliable. From a practical view-point it would be more logical to record laying dates than non-laying dates.

Short-period Recording instead of Yearly Recording

With the constant variation in the size of egg, it is evident that during a certain period of the year the pullet must lay eggs of a size which closely approximates the average annual size. Jull has suggested the first 10 eggs of March, whilst Maw and Maw have suggested the first 10 eggs of the fifth month of production.

An attempt was made to apply these suggestions to the foregoing records. It was immediately found inapplicable to individual birds, as

the majority were in a partial moult and not laying during the fifth month after production commenced. Jull seemed to find the same difficulty.

With each bird's record-sheet available, the averages were calculated of the last 10 eggs before laying ceased, and of the first 10 eggs after laying again commenced. From a practical standpoint it is impossible to record only the last 10 eggs, as one does not know when the hen will cease laying. The recording of the first 10 eggs when laying recommences can be practically carried out. It was found, however (see Table 2), that of the 55 hens only 3 laid without ceasing and only 2 others had not yet reached the average annual weight. For 50 birds, therefore, the average weight of the first 10 eggs was higher than the average annual weight.

TABLE 2. *Differences between Average Weights of Short-time Recordings and Mean Annual Weight of Eggs*

Difference between mean of last ten eggs before winter gap and annual mean weight			*Difference between mean of first ten eggs after winter gap and annual mean weight*		
Group I	*Group II*	*Group III*	*Group I*	*Group II*	*Group III*
−3·92	−2·83	−5·29	4·49	0·36	3·83
0·04	−9·98	No winter gap	3·60	4·22	No winter gap
0·34	−8·39	−6·10	4·60	2·24	3·12
−3·45	−2·56	0·30	3·82	−0·52	4·20
−9·14	−7·82	−3·30	−0·34	4·76	1·57
−1·73	−7·02	0·87	1·46	4·41	5·21
−6·06	No winter gap	−4·82	2·06	No winter gap	4·84
−4·82	−4·57	1·26	4·84	3·50	3·21
0·30	0·11	−0·35	6·92	5·22	1·69
−3·20	−8·38	−4·59	3·71	3·86	6·40
−8·15	−0·30	−2·63	2·74	4·91	5·25
1·87	−5·72	1·77	5·15	3·93	5·04
0·25	−6·21	−0·37	5·03	4·51	4·47
1·14	1·19	0·71	4·04	5·62	6·47
−6·05	−1·77	−3·88	4·76	1·15	7·30
−1·0	−1·99	−3·16	2·80	1·64	0·98
−10·41	−1·42	2·40	0·49	4·79	7·98
−4·56	1·49	−1·23	4·92	6·10	5·06
−1·60	..	..	4·23	..	..

A minus sign indicates that the average weight of the ten eggs is smaller than the average annual weight.

Seventy-two per cent. of the hens had not reached the average annual weight with the last 10 eggs before going into moult. From the above it is clear that the majority of birds in this experiment did not lay during that period when they would be laying eggs of a weight equal to the average annual weight. Therefore under conditions such as those under which these birds were kept, no short-period recording was found which could give a reliable estimate of the average annual size of egg.

To ascertain what effect the duration of the non-laying period had on the size of the eggs subsequently laid, the correlation coefficient was calculated between winter-gap period and the difference in weight of the average of the last ten eggs before cessation of laying and the first 10 eggs after laying recommenced. The values for r for Groups I, II, and III were $+0{\cdot}770 \pm 0{\cdot}096$, $0{\cdot}781 \pm 0{\cdot}097$, and $+0{\cdot}834 \pm 0{\cdot}076$, which are all positive and highly significant. Expressed differently, the longer the non-laying period the heavier are the first ten eggs when laying recommences.

One could conclude from the above that the inherent ability of gradually increasing the size of egg laid increases irrespective of the hen producing or not.

Conclusions

1. No significant correlation was found between the numerical production and the average annual egg-weight.
2. All three groups showed a positive correlation between maximum body-weight and average annual egg-weight, but those of the medium- and high-protein groups were alone significant.
3. Practically the same result was obtained when average body-weight was correlated with egg-weight, except that r for the high-protein group now also fell below significance, showing that in this experiment these two measures of body-weight differed in their relationship with egg-weight.
4. There was a positive, highly significant correlation between average monthly body-weight and egg-weight.
5. Winter-produced eggs (March, April, May, June) were highly correlated with annually produced eggs with respect to both number and size, thus indicating the possibilities of short-term recording.
6. There is also a high negative correlation between the number of days the bird ceases to lay and the annual production.
7. No period could be found when the average weight of 10 eggs was approximately equal to the average annual weight of eggs, because the moulting-period coincided with the period when such an equality would have been obtained.
8. There was a highly significant correlation between the number of days of the winter gap and the difference in the average weight of the last 10 eggs before laying ceased and the first 10 eggs after laying recommenced. This indicated that the longer the non-laying period the heavier were the first 10 eggs after laying recommenced.

Acknowledgement

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FORAGE-CROP PRODUCTION IN DRY-LAND AGRICULTURE AND ON RANGES IN WESTERN CANADA

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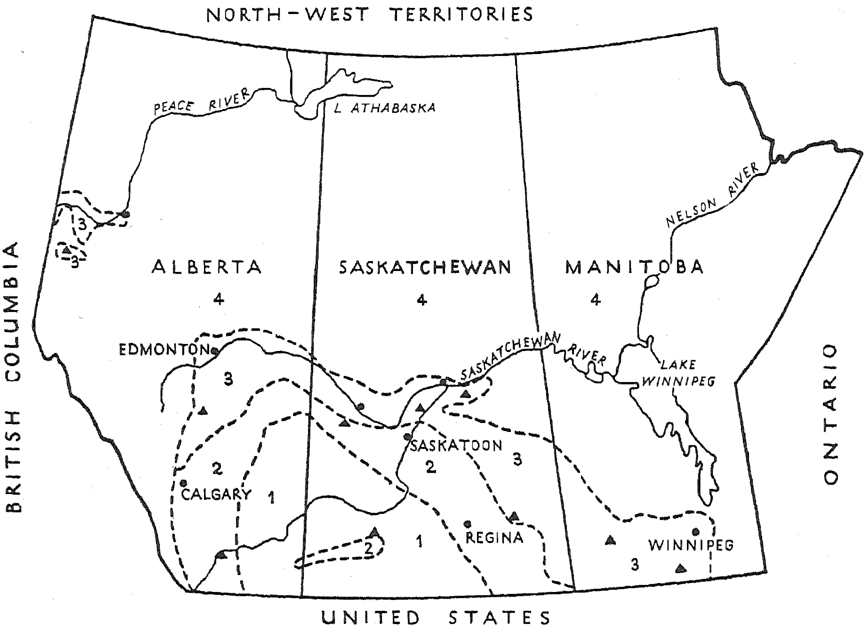
Introductory.—For those who are unfamiliar with western Canada it will be necessary to outline briefly the soil and climatic conditions which characterize the area discussed in this paper. Reference to the accompanying sketch-map of the three prairie provinces will serve to indicate



Sketch-map of the Prairie Provinces of Western Canada, showing Major Soil Zones and Location of Dominion Experimental Stations

1. Brown-soil zone (semi-arid, short-grass prairie).
2. Dark-brown-soil zone (semi-arid to sub-humid prairie).
3. Black-soil zone (sub-humid 'parkland').
4. Grey-soil zone (sub-humid wooded land).

▲ Location of Dominion Experimental Station.

the relative positions of Manitoba, Saskatchewan, and Alberta in relation to Ontario on the east, British Columbia on the west, and United States on the south. This map was very kindly prepared for the writer by Mr. H. C. Moss, Soils Department, University of Saskatchewan, and may be regarded as authentic in respect to the zoning of major soil types. The dotted line separating Zone 3 from Zone 4 could have been taken,

until comparatively recent years, as approximately the northern limits of settlement, but now a considerable area in Zone 4, especially in Saskatchewan, has been 'homesteaded'. Practically all of this land is wooded, and as yet the clearance per farm is small. The main cultivated area comprising Zones 1, 2, and 3 extends from the eastern boundary of the Red River valley in Manitoba to the foot-hills of the Rocky Mountains in Alberta, and from the 49th parallel of latitude for a distance northward of about 350 miles.

The major soil zones, as outlined in the sketch-map, reflect soil differences associated with variations in climate and native vegetation. The brown-soil zone is a semi-arid country of short-grass plains with an annual precipitation of 11 to 14 in. The moisture-efficiency in this zone is low, owing to relatively high mean temperatures and warm, drying winds. A considerable proportion of this area is devoted to ranching, more especially the western portion of Alberta and the south-western corner of Saskatchewan. Most of this area, which lies in Saskatchewan, is, however, devoted to the production of wheat. Farming practices adapted to extensive cultivation and approved methods of moisture-conservation are therefore of the utmost importance.

Zones 1, 2, and 3 form a natural sequence with increases in precipitation and moisture-efficiency. Increase in total precipitation is slight in Zone 2, but more pronounced in Zone 3, with variations from 15 to 20 in. The increase in moisture-efficiency, on the other hand, is much more important, being associated with a decrease in mean temperature and a reduction in the duration and velocity of drying winds.

The northern and eastern limits of Zone 2 coincide approximately with the transition from true prairie to partially wooded prairie or 'parkland'. There is also a corresponding change from soils of a dark-brown or chestnut colour to soils that are predominantly black. Variations in precipitation and moisture-efficiency appear to be primarily responsible for these pronounced differences in vegetation and soil characteristics.

The dominant factor in crop production in all three soil-climatic zones is undoubtedly that of available moisture. In Zone 1 crop failure frequently results from drought, and this also occurs to a somewhat less extent in Zone 2. Even in Zone 3 moisture is the main factor limiting plant-growth, but moisture conditions on the whole are here much more favourable than in Zones 1 and 2. Variations occur also from year to year in the incidence of favourable and unfavourable moisture conditions, as in 1934, when the area affected by drought was much more extensive than usual, and the centre of greatest severity was farther to the east.

Seasonal variations in the annual precipitation are considerably greater than the zonal variations. The greatest amount of precipitation recorded in one year has been from two to four times greater than the lowest, depending upon location. Long-time precipitation trends show that wet and dry years seldom occur singly, and that more or less well-defined cycles can be distinguished in which several years of more than average rainfall alternate with several years of comparatively dry weather. Precipitation, of course, is notoriously variable from year to year all over the world, and western Canada is no exception in this respect. It is only

because a surplus of subsoil moisture never occurs in Zones 1 and 2, and very rarely in Zone 3, that the seasonal variations in precipitation often make all the difference between years of drought and years of plenty.

In addition to limited supplies of available moisture, the rather short growing-seasons and extremes of temperature, both daily and seasonal, impose rigorous restrictions on the choice of forage crops. Most of the commonly grown grasses and clovers, including timothy, cocksfoot, Italian and perennial rye-grasses, red clover, alsike, and white clover, are ill adapted, either because of their moisture-requirements or lack of winter hardiness. Only in a few restricted areas of Zone 3 can such crops as timothy, red clover, and meadow fescue be used to advantage.

Maize is grown to a considerable extent in southern Manitoba, more especially in the Red River valley south of Winnipeg, where early-maturing dent varieties produce good fodder crops, due to the lower altitude and mean temperatures that are higher than elsewhere. This crop is also on the increase in southern Alberta, but only the very early flint and dent varieties are satisfactory because of the higher elevation of this area. Across the northern settled portion of the three prairie provinces the growing of maize has not attained much success. Throughout the Park Belt and adjacent plains sunflowers provide a high-yielding ensilage crop, but the labour required in handling is heavy, and the absence of silos for storing the fodder has, to date, prevented the sunflower crop from becoming of any importance.

Hay and Pasture Crops

The amount of cultivated land devoted to hay and pasture crops in the three western provinces has been relatively unimportant as compared with the total of 40 million acres which are seeded annually. Statistics show that hay and pasture occupy roughly 5 per cent. of the land devoted to field crops, about half of which, or one million acres, is seeded pasture. These figures, taken by themselves, are, however, misleading, in that they do not include cereal crops that are pastured or harvested in the sheaf for hay. The latter, in western Canada, is very important. Oats alone are grown more extensively for 'feed' than all other forage crops combined. The estimated area of natural pasture is 29 million acres, of which about 7 million acres of ranching country are leased for grazing purposes, mostly in Zone 1.

There are natural and obvious reasons for the disparity between cereal and forage crops in a new country like western Canada, but soil and climatic conditions cannot rightly be classed among them, except in those areas where lack of moisture makes even grain-growing hazardous. Even this disability is being overcome by the introduction of forage plants that are exceptionally drought-resistant. Everywhere the yield of forage is limited by the amount of available moisture, and this is to be expected. On the other hand, the soil in general is exceptionally favourable for grasses and legumes, being naturally fertile and plentifully supplied with lime. Fortunately, there is available a sufficient number of species that are winter-hardy and remarkably well adapted to the prevailing conditions.

Perennial grasses.—There are three species of perennial grasses that are highly adapted to this area. These are brome grass, *Bromus inermis*; slender wheat-grass, *Agropyron tenerum*; and crested wheat-grass, *Agropyron cristatum*. A choice between these should be governed chiefly by the purpose for which the grass is grown, the soil type, and moisture conditions. Broadly speaking, crested wheat-grass is highly adapted to the brown-soil zone, whilst brome grass and slender wheat-grass are best adapted to the dark-brown and black-soil areas.

Crested wheat-grass, being exceptionally resistant to drought, will do better than the other two where this property is of first importance. Western rye-grass does exceptionally well in the Park Belt, and many farmers there prefer it to brome grass because it is not stoloniferous and is therefore easy to control by ploughing. Generally speaking, the growing of slender wheat-grass is on the decrease, because its performance has been disappointing in the recent dry seasons. This is particularly true of the prairie sections. Brome grass has been the most important grass in the central or dark-brown-soil area, because it withstands drought better than slender wheat-grass and is altogether a better pasture crop. The use of brome grass is increasing, especially in Manitoba, where it is grown more extensively than any other species. Although it is sometimes discounted by farmers in the more humid districts and on heavy soil owing to its strong underground stems, it deserves to be grown even more widely than it has been because of its productiveness, palatability, and high nutritive value. It thrives on a wide range of soil types, being particularly useful on the lighter soils, where it should be grown in preference to slender wheat-grass. Brome grass is a good seed-producer and the herbage remains green after the seed is ripe. Both for hay and pasture it is a superior grass.

Crested wheat-grass has been grown in a small way in western Canada during the last few years, but only now is it coming into general use. Experimental work with this species indicates that it is one of the most valuable species that has ever been introduced into western Canada, and that it promises to provide a much-needed perennial hay and pasture crop for the semi-arid sections of the West. At Saskatoon, crested wheat-grass has yielded at least as much as brome or slender wheat-grass over a six-year period. In general, it may be said that crested wheat-grass will produce more or less than slender wheat-grass or brome grass in proportion to the abundance or scarcity of available moisture. In the very dry season of 1931 it produced double the yield of either brome or slender wheat. It is high in feeding-value, withstands grazing well, does not become root-bound, provides feed in the early and late parts of the season, and produces seed abundantly.

Alfalfa.—Alfalfa is highly adapted to the black-soil zone or Park Belt, and in favourable seasons good crops are secured also on the better soils in Zone 2. Western Canada is self-supporting with respect to seed-production of hardy strains, of which by far the most important variety is 'Grimm'. When sufficient attention is given to proper management of the crop there is seldom much trouble with winter-killing. In favourable seasons two crops of hay can be taken, but very often it is more

profitable to take only one. The latter practice ensures an adequate storage of root-reserves, and provides the best guarantee against winter injury. Cutting of the second crop is hazardous when it is done just early enough to permit of some autumn growth, but too late to enable the plants to replenish their root-reserves.

Mixtures versus single species.—For the most part the different kinds of perennial grasses and alfalfa are grown in pure culture, but many farmers now seed the grasses with alfalfa in a mixture, and this practice is on the increase. In an experiment extending over eight years which the author conducted at the University of Saskatchewan, slender wheat-grass, brome grass, and alfalfa were compared from the standpoint of yield of hay. Each crop was seeded alone and each was combined with the other in mixtures. The results of this test, which included 18 crops of hay, showed no significant differences between the yields of any one of the three crops, nor between these and a combination of the two grasses. This was explained on the basis that moisture was always a limiting factor in growth and that each of the three species separately, and the mixtures, used up annually all the available moisture. Thus the yields were strictly limited.

Mixtures of slender wheat-grass and alfalfa, and of brome grass and alfalfa, on the other hand, did yield significantly more than any of the single species seeded alone, or of the two-grass mixture. This indicated an increase in moisture-efficiency when the grass and legume were grown together. There was also an obvious difference in vigour of growth and depth of green colour between the grasses growing in association with alfalfa and of those growing by themselves. Apparently the grass was benefited by the alfalfa, presumably because of the latter's ability to utilize atmospheric nitrogen. By taking samples for chemical analyses in each of two years it was found that the brome grass growing with alfalfa contained 16 per cent. more protein than it did when growing alone. The increase in protein shown by slender wheat-grass in association with alfalfa was still greater, being almost 40 per cent. Not only therefore did the grass-alfalfa mixture give a significantly greater quantity of herbage, but the feeding-quality of the grass itself was improved and that of the mixture enhanced by the legume constituent.

One complete series of these plots, seeded in 1926, has been retained until the present time, and in 1934, the eighth crop-year and an exceptionally dry season, the mixture of brome grass and alfalfa was more than twice as productive as the brome grass on adjacent plots, and considerably more productive than the alfalfa alone. The proportion of brome grass and alfalfa in the herbage has remained fairly constant from year to year, showing that these species are quite compatible. The mixture of slender wheat-grass and alfalfa, on the other hand, has not maintained its productivity because the grass constituent has suffered severely through the intervening years, several of which have been particularly dry.

Sweet clover.—Sweet clover has been a very welcome and valuable addition to the forage crops that can be grown in western Canada. It is a biennial and therefore must be seeded each year. The crop is utilized

for hay or pasture in the year following seeding. Two crops of hay can sometimes be secured in a single season, but the more common practice is to cut one crop of hay and pasture thereafter.

Sweet clover can be grown successfully over practically all of the western plains area. Few crops are adapted to such a wide range of soil and climatic conditions, and probably none will produce as much good pasturage. Sweet clover has been the salvation of many a farmer in very dry years, giving a fair yield under conditions which resulted in complete failure of perennials. When moisture is plentiful, on the other hand, sweet clover will take full advantage of it.

Good stands of sweet clover are difficult to obtain under unfavourable moisture conditions, such as occur frequently in the brown-soil zone. This is especially true if the clover is seeded with grain as a nurse-crop. Perhaps the most frequent cause of failure with sweet clover is seeding too deeply into loose soil. This is fatal. The grower of sweet clover must learn the all-important principle that shallow seeding on very firm soil is the best insurance that he can have for securing good stands of this crop.

Rather severe losses of sweet clover have occurred from time to time from the ravages of cutworms, which are very fond of this species, and also from certain native soil organisms that cause rotting of the roots in the early spring of the second season. The latter have not been troublesome in Manitoba but rather severe in Alberta, and the injury is much worse in some years than in others. Apparently much depends on the vigour of growth and size of roots as they go into the winter; the larger the roots the less is the injury likely to be. It has been found that seeding without a nurse-crop not only produces larger yields the following season but also greatly reduces the hazards from root-rot. Although the practice is not common, there is much to be said for seeding in some sections of the country without a nurse-crop in June, after the danger from cutworms is past, rather than seeding with grain in the early spring. When sweet clover is grown with a nurse-crop early seeding is preferable.

Crops for alkali soils.—In many parts of the West one frequently encounters soils in which the concentration of alkali salts tends to be excessive for plant-growth. Based on tests which were conducted at the University of Saskatchewan, the forage crops most tolerant of alkali salts were found to be sweet clover, slender wheat-grass, brome grass, and crested wheat-grass.

Difficulty is sometimes experienced in securing a stand of sweet clover on alkali soil because the seedlings are liable to be injured in the early stages of growth, but when they have become established the clover is much more tolerant and will grow where the alkali salts are toxic for cereal crops. If the sweet clover is grown continuously for three or four years on such land, the condition is frequently sufficiently improved so that oats or even wheat can be produced. A top dressing of well-rotted manure 'disked' into the land before seeding helps considerably to get sweet clover started.

When seeding-down a field which is spotted with alkali, it is a very good idea to use a mixture rather than a single species of alkali-tolerant

plants. The chances of getting a satisfactory stand are better, and each component of the mixture will tend to become established where it is best suited. A good mixture for this purpose consists of 7 lb. of slender wheat-grass, 7 lb. of brome grass, and 10 lb. of sweet clover, making 24 lb. of seed per acre.

Annual crops for hay and pasture.—The importance of annual forage crops in western Canada can scarcely be over-estimated. Of these, oats are by far the most important and the most valuable for feeding stock, whether as hay or pasture. They excel in both yield and quality of forage, and few, if any, other crops are as satisfactory when used as the sole ration for horses and cattle. Barley is valuable also as a feed-crop, but bearded varieties are objectionable. Spring rye produces a crop of somewhat inferior hay which sometimes comes in handy when feed is scarce, because it can be cut early. Autumn rye has most value as a pasture crop in late autumn and early spring, but it may also be harvested for hay. Peas are grown with oats to some extent in the more humid districts and with excellent results. Millet is useful as a quick-growing catch-crop to seed late, but it does not do well under dry conditions, and it is inferior to oats in yield and feeding-quality.

Reliance must be placed on cereals also for annual pasture. Here again oats are the best, but either wheat or barley in admixture with oats may be seeded with good results. A favourite mixture for pasture in many parts of the West is a combination of two bushels of oats and one of autumn rye per acre; the latter tends to produce a leafy bottom growth during the first year, and this provides good pasturage late in the season after the oats are done.

Seed-Production

Conditions in the prairie provinces are very favourable for growing seed of all the important forage crops that are adapted to that area. Sweet-clover seed is grown extensively in all three provinces. Some slender wheat-grass seed and brome-grass seed is grown in Alberta and Manitoba, but Saskatchewan produces about three-quarters of the supply. Until recently, most of the alfalfa seed was grown under irrigation in the district which centres about Brooks, Alberta, but it is now being produced in considerable quantity by all three provinces. With crested wheat-grass it has been found that in Zone 1, where it is best adapted and most useful, the supply of available moisture after the grass has headed may be insufficient properly to fill the seed. The seed crop, therefore, may be a failure, and even in favourable seasons the yield is likely to be much less than if the grass were grown farther north in the Park Belt, where better moisture conditions prevail. Whereas a good crop of crested wheat-grass seed in Zone 1 may be about 200 lb. per acre, it is not uncommon in Zone 3 to secure 500 or 600 lb. of seed per acre. The bulk of the seed, therefore, is likely to be grown in the northern part of the three prairie provinces and used in the southern part. For seed-production this grass is grown in inter-tilled drills about 3 or $3\frac{1}{2}$ ft. apart.

What has been said with respect to crested wheat-grass applies also

to brome grass, slender wheat-grass, sweet clover, and alfalfa. In the Park Belt moisture conditions are exceptionally favourable for seed-production, whereas in the driest parts of the prairie area seed-production of these crops is precarious.

Methods of Seeding

In seeding-down with grasses and legumes it is of vital importance to get good establishment. This presents certain difficulties in semi-arid and sub-humid areas, where good rains are apt to be somewhat infrequent and the top-soil rapidly dries to a depth of 1 or 2 in. In very dry seasons it is almost impossible to secure good stands of grasses and legumes, but in most years there is sufficient moisture near the surface in the early part of the season and sufficient precipitation from time to time during the spring months to ensure success if certain fairly well-established principles are observed.

Seeding-down with a nurse-crop of grain is a common practice, because a crop of grain or sheaf feed is secured in the year of seeding. On land that is weedy or liable to soil-drifting also, a nurse-crop has obvious advantages. The usual practice is to mix thoroughly grass seed with grain and sow both together with the ordinary grain-drill. A nurse-crop, however, makes heavy demands on the soil moisture, and competes so strongly with grasses and clover that the latter may be completely killed in a dry season. Therefore, if a nurse-crop is used in the prairie sections which are less favourably situated with respect to moisture, early seeding on land which has reserve moisture, such as summer fallow, is highly desirable.

It frequently happens, however, that seeding of grasses and clovers is done on land which has little or no reserve moisture, and which in the normal grain-rotation would be fallowed in summer. Under these circumstances grasses and clovers can be started with greater safety if no nurse-crop is used. The land should be ploughed or surface-worked early in the season, packed to start weed seeds, and kept clean until after rains, which are most likely to occur in June; then, if the grass and clover seed is shallow drilled, without a nurse-crop, there is an excellent chance of getting a good stand well established before fall. This applies particularly to brome grass, slender wheat-grass, alfalfa, and sweet clover, but with crested wheat-grass it is always safer to seed very early whether with or without a nurse-crop, because the young seedlings of this species get started much better in cold weather.

In seeding grass and clover seed, drilling is preferable to broadcasting, but with the former method great care is necessary that the seeds are not sown too deeply. This is difficult to avoid with a grain-drill unless the soil is very firm and unless all pressure is released from the disks which act as soil-openers for the seed. The maximum depth of seeding for crested wheat-grass, sweet clover, brome grass, alfalfa, and slender wheat-grass should be $\frac{3}{4}$, 1, $1\frac{1}{2}$, $1\frac{1}{2}$, and 2 in., respectively. These depths are less than that commonly employed for cereals. A method of seeding with a nurse-crop which gives excellent results but requires somewhat more work, is first to drill the grain separately, and then to

drill the grass or legume seed crosswise. In this way both can be seeded at depths which are most suitable.

Shallow seeding on well-prepared and very firm soil is of first importance in securing good stands, especially of crested wheat-grass and sweet clover. Many failures result from lack of appreciation of the importance of these simple pre-requisites. Even with the best intention it is often difficult to drill shallow enough on spring-prepared land, because the weight of the drill tends to force the disks too deeply. This is the case to such an extent that with crested wheat-grass and sweet clover, broadcasting is often the safer method, particularly when seeding can be done early while moisture is still close to the soil surface.

Range Investigations

An extensive study has been made during the last six years at the Dominion Range Experiment Station, Manyberries, Alberta, on the effect of different systems of range-management on the native vegetation. These methods include continuous, deferred, and rotational grazing. Over-grazing has been responsible, more than any other factor, for the depleted condition of certain range areas. It seems clear that the most economical way of restoring depleted pastures on the range is to protect them during the spring and summer months and then to graze in the autumn and winter after the seeds of native grasses have been shed. If the pasture is badly depleted this method of deferred grazing should be adopted several years in succession.

Although deferred and rotational grazing is recommended, the range should not be divided into units which are too small, or the grass-cover will be injured by excessive tramping. Uniform grazing can be obtained by good distribution of watering-places and salt-boxes. Areas that have been closely grazed in autumn should not be pastured in the spring. On spring pastures there should be a carry-over of at least 30 per cent. of the previous year's grass.

Many tests have been made on the re-seeding of depleted range land. These have proved successful only where the native grasses have been almost completely killed out. Where there still remains even a thin stand of native grass it is probably better to protect the area from grazing, or to graze only during late autumn, thus allowing the grass to go to seed and spread naturally.

Seeds of many species of grasses and legumes have been tried for re-seeding fields which were once cultivated and since abandoned. Crested wheat-grass has given by far the best results. Good stands of this grass have been obtained by scattering the seed among the weeds, either late in autumn or early in spring, giving a single disking after seeding. With this treatment crested wheat-grass produced a good growth in 1934, after being closely grazed each summer from early spring until late autumn for six years in succession.

Charted quadrats and permanent enclosures have been established on each of the nine fields used in the investigation of grazing capacity, and also on four large fields assigned especially for this study. In addition, the vegetation-cover of each field was carefully examined three

times each season: before grazing began, about mid-season, and at the time the cattle were removed from the field. In general it was found that fields grazed at the rate of 20 acres per head were much overgrazed. Those grazed at 30 acres per head were slightly overgrazed, whilst pastures grazed at 40 acres per head were undergrazed.

The identification of native forage plants of the short-grass plains has been completed, and a key has been prepared for the grasses of the prairie provinces. Considerable attention has been given to the effect of climatic conditions on plant-growth and to other ecological problems.

Chemical analyses of the native species show that they are high in protein when in the leaf-stage, and that at this time they contain also sufficient phosphorus and calcium to meet the animals' requirements. As the plants approach maturity there is a marked drop in nitrogen and phosphoric acid. As cured grass for late autumn and winter grazing, there is a deficiency in the phosphorus-content of these species. Calcium-content does not drop to any considerable extent. To overcome this lack of phosphorus in the native herbage some stockmen are now beginning to feed mineral supplements of bone-meal or monocalcium phosphate.

The production of winter feed on the range is a matter of considerable importance, as reserves of hay are essential in case winter grazing conditions become difficult. The development of comparatively small local irrigation schemes by the construction of dams for impounding the spring run-off water has been found to be one of the best ways of solving the winter-feed problem. With a comparatively limited application of water by surface-flooding, excellent crops of alfalfa hay can be produced. Alfalfa is by far the best cultivated crop for this purpose. In certain places the native grasses produce well where water is supplied. Some ranchers, in favourable locations, practise dry-land farming. The land is alternately cropped and summer-fallowed to conserve moisture, and such crops as the cereals, sweet clover, and maize are produced for forage.

In southern Alberta there are several large-scale irrigation projects not far removed from the ranching areas, and there is a growing tendency for the irrigation farmer who can grow large quantities of feed, on the one hand, and the rancher who produces the animals, on the other, to work out arrangements that are mutually advantageous, involving the establishment of winter feed-lots close to crop-production areas.

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PASTURE STUDIES VII. THE EFFECT OF FERTILIZATION ON THE NUTRITIVE VALUE OF PASTURE GRASS

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Introductory.—The literature dealing with this subject has been reviewed and discussed in an earlier paper [1] where the general reasons for this series of studies[1] were outlined.

The failure of previous studies adequately to explain observed differences in the nutritive value of herbage from different pastures, and of differences resulting from the application of fertilizers, led to the suggestion that quality of protein might be a factor of importance and one hitherto disregarded in pasture studies. Accordingly, a series of feeding tests was planned to determine, if possible, (1) whether pasture herbage might be deficient in any one of the essential amino acids, and (2) whether the oft-observed increase in nutritive value due to fertilizer treatment might possibly be the result of an improved amino-acid balance of the herbage.

It was realized, of course, that fertilization of pastures often affects the botanical composition of the mixed herbage, and, therefore, that tests would also need to be made on the pure species, both untreated and fertilized, which contributed to the mixed herbage of the pasture studied. Arrangements were made to secure such clippings from the experimental plots of the Agronomy Department.

Experimental.—The plan of the experiment involved the feeding of grass clippings with and without supplements of single purified amino acids or combinations of them.

The difficulty in obtaining grass clippings in large quantities and the cost of the amino-acid supplements necessitated the use of laboratory animals in this study, and rabbits were chosen as the most suitable because of the similarity of the natural diets of domestic rabbits to those of farm ruminants. Excepting as otherwise noted, rabbits raised from a small breeding unit maintained for the purpose, and weaned at approximately seven weeks of age, were used in all tests of this series. A preliminary feeding-period of from one to three weeks was usually found necessary to accustom the rabbits to the individual cages and the finely-ground grass.

The feeding trials herein reported represent but the first trials of the series involved in the project. For these tests either crude lactalbumin or cystine-fortified casein were used as supplements carrying a complete

[1] These studies constitute a part of the general pasture project undertaken at Macdonald College, and are made possible by financial assistance from the Quebec Department of Agriculture.

assortment of the essential amino acids. In so far as the single amino-acid supplements were concerned, it was decided to confine the first year's tests to cystine, partly because there was some indication from the literature that pasture herbage might be deficient in cystine, and partly because of cost.

The mixed pasture-grass clippings used in the first year's trials were obtained from pasture lands of two farms in the Eastern Townships of Quebec co-operating in the Macdonald College Pasture Project.

In the spring of 1933, one-half of each of these areas received 100 lb. of potash and 500 lb. of superphosphate (16 per cent.) per acre, and was fenced to permit controlled grazing. Three clippings were made during the season, and after each clipping cows were allowed to graze the areas. The first clipping was taken during the second week in June and represented the spring growth of grass. The pastures were then grazed for about two weeks, after which the cows were taken off to allow the grass to grow for the second clipping, which was made during the last week in July. The grass at this time was not plentiful, owing to the exceptionally dry summer, and hence no clipping was taken in August. The areas were grazed after the second clipping but were kept ungrazed about a month before the third clipping, which was made during the last week in September.

The clippings were dried in the field until in suitable condition to ship, when they were forwarded to the laboratory and drying was completed by spreading in a thin layer on the floor. When dried, the grass was ground in a hammer-mill and stored in bags until required for feeding.

The clippings of pure species of grass, obtained from plots of the Agronomy Department, were prepared for feeding in the same way as were the samples of mixed pasture herbage.

Since an accurate and detailed record of feed-consumption seemed essential in this study. individual feeding was employed. The equipment used has already been described [1].

TEST I. *Timothy* v. *Reed Canary-Grass*

This test was planned to compare the nutritive value of immature timothy grass with that of immature reed canary-grass; also to determine whether the addition to these grasses of a protein of high biological value would increase their nutritive values. Besides the four rations necessary for these comparisons, a fifth, thought to be satisfactory for normal growth, was included as a check ration.

A sixty-day feeding period was used in this test. To follow the progress of the rabbits during the trial, live weights and feed-consumption were checked at ten-day intervals.

Feeds used.—The reed canary-grass and the timothy were cut from plots of the pure species in the early summer of 1933. The grass was cut when it was from 4 to 6 in. high, and as it was desired to obtain the grasses at the same stage of maturity, the timothy, which grows less rapidly, was cut about a week later than the reed canary-grass. Crude lactalbumin[1] was used as a protein supplement. The oats, linseed meal,

[1] The lactalbumin used was obtained from the Quinty Dairies, Wellington, Ontario.

and alfalfa meal were obtained from the feed-supply of the College Stock Farm.

Rations fed.—The details of the rations, together with their chemical analyses, are given in Table 1. The animals were fed *ad libitum* throughout the experiment.

TABLE 1. *Timothy* v. *Reed Canary-grass*

Rations used and their chemical composition

	Lot I	*Lot II*	*Lot III*	*Lot IV*	*Lot V*
Reed canary-grass	100	..	95	..	..
Timothy	..	100	..	95	..
Alfalfa meal	..	..	..	..	50
Oats	..	..	..	..	40
Linseed meal	..	..	..	..	10
Lactalbumin	..	..	5	5	..
Analysis as per cent. of dry matter:					
Crude protein	13·53	12·01	15·88	14·41	15·20
Ether extract	3·10	3·69	2·99	3·55	3·68
Crude fibre	27·83	26·82	26·42	25·48	22·98
N-free extract	45·27	49·39	43·77	47·69	53·07
Total ash	10·27	8·09	10·94	8·87	5·07
Ca	0·417	0·398	0·437	0·418	0·715
P	0·388	0·349	0·392	0·354	0·388

Animals used and allotment.—Twenty-five rabbits of approximately ten weeks of age were used in this experiment. They were divided as equally as possible into five lots, taking into consideration chiefly weight, sex, and condition. The average weights for each group ranged between 1,304 and 1,321 grammes at this stage. The animals were fed on their respective diets for a preliminary period of five days before the actual experiment began and the data (Appendix, Table 1) were first recorded.

Observations.—During the first ten-day period a serious loss in weight and condition occurred in the animals on reed canary-grass (Lots I and III). One animal in each of these lots died during this period. Post-mortem examination showed that both of these animals had diseased kidneys and hearts. Consequently, they were replaced on the first weigh day by two extra rabbits which had been carried as spares. The animals receiving timothy (Lots II and IV) also lost their original bloom during the first period, though they continued to grow and actually gained in weight. The animals receiving the check ration (Lot V) showed no loss in condition and grew rapidly.

As shown in Fig. 1, all lots showed gains in weight after the first period. The gains, however, in Lots I and III were small. No consistent improvement over Lot I could be noticed from the addition of lactalbumin to the reed canary-grass in Lot III.

During the third period one animal in Lot I died. Post-mortem

Analysis showed it to contain 94·7 per cent. dry matter, having a percentage composition of crude protein 59·28, ether extract 0·89, fibre 0·47, nitrogen-free extract 16·17, ash 23·19 (Ca 8·15, P 4·51).

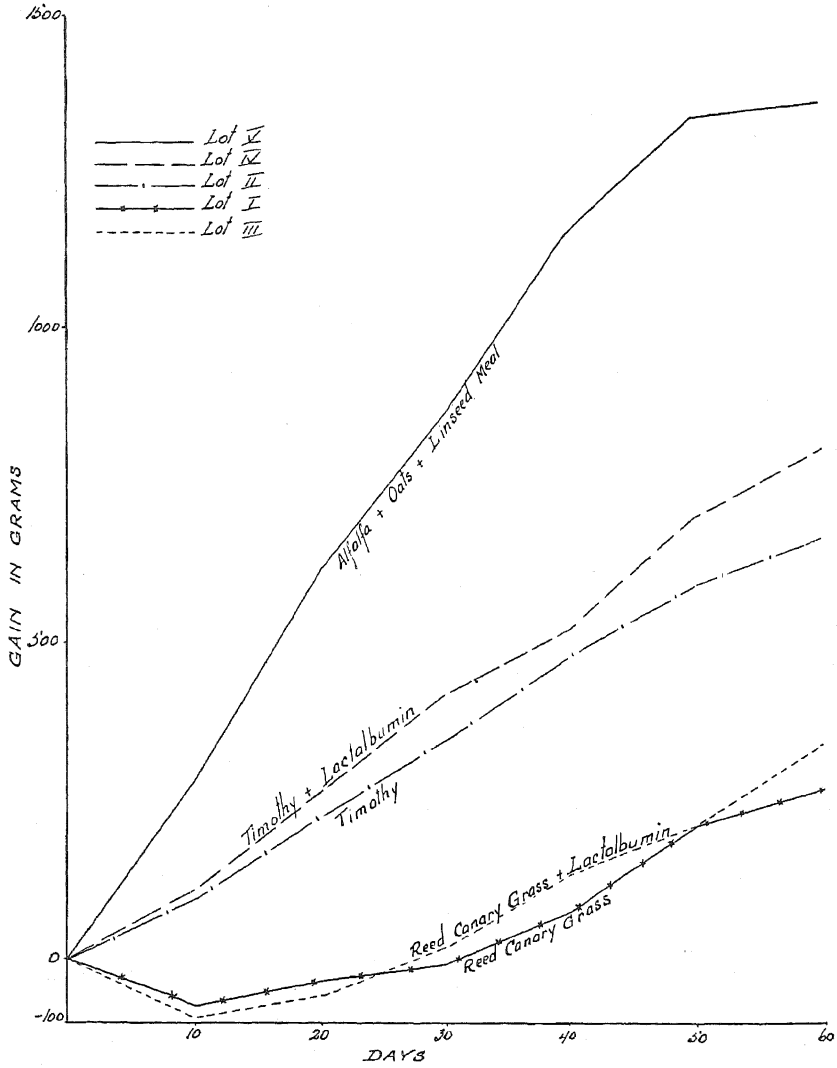

FIG. 1. Timothy *v.* Reed Canary-Grass.

examination showed no abnormalities except thin brittle bones and precipitated calcium oxalate in the urine. The prevalence of leg injury in the remainder of the animals in Lot I was a peculiar feature in this group. Three out of the four animals were lame at various times during the trial. In no case was the injury serious, and their recovery, without treatment, was complete before the end of the trial; but the fact that it occurred only in one lot is perhaps significant.

Lots II and IV (timothy) gained consistently throughout the feeding-period and appeared healthy and in good condition. The addition of

protein to the timothy diet produced a noticeable though not a marked improvement.

The control animals (Lot V) made normal gains. At the close of the experiment they were approaching maturity and their rate of growth began to slacken.

The data.—The details of initial weights, feed-consumption, and gains, together with the statistical analysis of the gains are given in Appendix, Table 1. The gains are given in graph form in Fig. 1.

The consistency of the gains made by the animals on timothy (Lots II and IV) is noteworthy, as also is the consistent but small increase in the gains of Lot IV over Lot II, due to the addition of 5 per cent. lactalbumin. The gains of the animals on reed canary-grass (Lots I and III) showed more variability than was found in other lots.

For inclusion in the statistical analysis the gains and feed-consumption for rabbit No. 27, which died on the 16th day of the experiment, were calculated by the method of Yates [2].

Statistical analysis was applied to the data, using the method of partial regression, as described by Crampton and Hopkins [3], by means of which the combined effects on gains of differences in initial weight and differences in feed-intake of individual rabbits are removed, thus permitting an estimate of gains expected from the trial had all animals been of the same weight at the start and consumed equal quantities of feed during the test. The corrected mean gains for each lot are shown in Table 2.

TABLE 2. *Timothy* v. *Reed Canary-Grass—Mean Gains (to nearest whole gram)*

Lot I	*Lot II*	*Lot III*	*Lot IV*	*Lot V*
Reed canary-grass	Timothy	Reed canary-grass + lactalbumin	Timothy + lactalbumin	Alfalfa meal + oats + linseed meal
287	641	390	870	1,263

In this trial, and considering odds of 19 to 1 as necessary for significance, any difference between mean gains greater than 119 gm. may be taken as a real difference due to difference in the nutritive value of the ration. From this analysis it is evident that the difference between the mean gains of the animals on timothy (Lot II) and those on reed canary-grass (Lot I) is highly significant. The addition of 5 per cent. lactalbumin to the reed canary-grass (Lot III) produced no significant increase over Lot I; but the addition of lactalbumin to the timothy (Lot IV) increased the gains significantly over those of Lot II. None of the rations was so satisfactory as the check ration, as measured by gains in live weight of the animals.

Summary.—In the light of the foregoing results it seems evident that the nutritive value of immature timothy is greater than that of immature reed canary-grass. This superiority cannot be explained on the basis of quantitative differences in crude protein, calcium, phosphorus, or

total nutrients, for in these respects these grasses were very similar (Table 1). Observations during the trial, substantiated by the data on feed-consumption, showed no difference in the palatability of the two grasses as measured by the quantity eaten by the animals.

TEST II. *Fertilized* v. *Unfertilized Pasture Grass*

This experiment was planned to test the nutritive value of fertilized and unfertilized pasture grass by feeding the herbage, unsupplemented, to young rabbits. The feeding-period was twenty-eight days continuously, live weights and feed-consumption being recorded at seven-day intervals.

Feeds used.—The source and preparation of the herbage used in this experiment have been described (p. 332), and the botanical and chemical composition of the herbage have already been detailed [1]. Chemically, the fertilized herbage fed to Lot I was somewhat higher in protein than that from the unfertilized areas (16·7 and 14·7 per cent. protein, respectively); other differences were small. Botanically, the fertilized herbage carried considerably more white clover and correspondingly fewer weeds.

Animals used and allotment.—Animals from the regular breeding unit were not available for this test, but it was found possible to secure from another department chinchilla rabbits of approximately ten weeks of age. They were somewhat smaller (due to difference in breed) than those used in other tests and also less uniform in size. They were allotted by pairs to two groups, weight, sex, and condition being taken into consideration.

Observations.—The chinchillas were often found more delicate than the larger breed regularly used. We were not greatly surprised, therefore, that two of the smaller animals in each group died during the first week of the experiment. Post-mortem examination revealed a diseased liver in one rabbit. This condition, however, could not have developed as a result of the experimental diet. No abnormalities were found in the other three animals.

The eight rabbits remaining, which for the most part were larger animals, adapted themselves satisfactorily to the diets. The results from the animals that died were therefore discarded and the two (one in each lot) whose pair mates had died became the fourth pair (Nos. 7 and 12).

A marked difference was noticeable during the experiment in the condition of the animals in the two lots. Those on the fertilized grass (Lot I) were in good condition throughout the trial and made fairly rapid growth. The animals on unfertilized grass (Lot II) began to fail in condition immediately after the trial had commenced. This loss in weight and condition continued for the first three weeks of the experiment, until, in most cases, the animals became emaciated. During the last period, however, every animal in the lot showed a slight increase in weight. Post-mortem examinations, made on representative animals after the experiment finished, showed the animals to be normal and disease-free.

The data.—The details of the initial weight, feed-consumption, and gains, together with the statistical analysis of the gains, are given in Appendix, Table 2.

The gains are shown graphically in Fig. 2. The difference in the mean gains of these lots is statistically significant. This analysis, however,

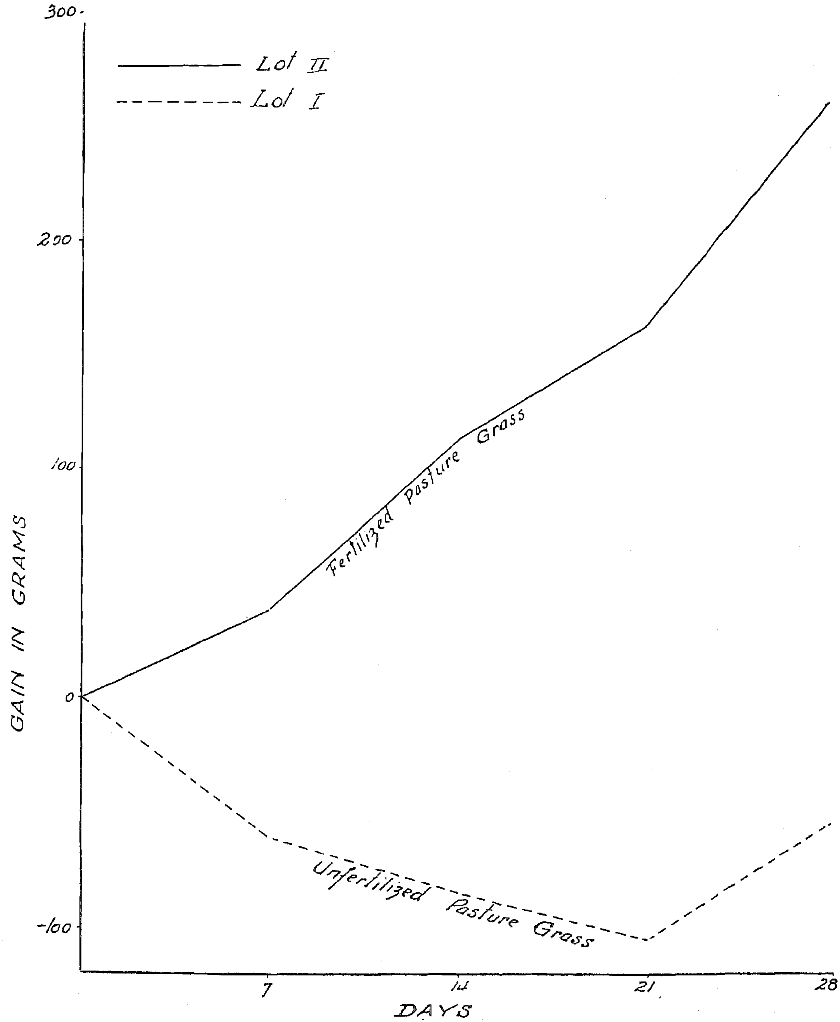

FIG. 2. Fertilized *v.* Unfertilized Mixed Pasture Herbage.

did not take into account differences in initial weight or in feed-consumption. It is realized that the average daily feed-consumption was about 4·5 per cent. higher for Lot I than for Lot II, but it does not seem likely that this small difference was responsible for the difference of some 300 per cent. in gains.

Summary.—The results of this experiment indicate strongly that

there may be a marked difference in the nutritive value of herbage from pastures treated with mineral fertilizers as compared with herbage from similar unfertilized pastures. That a part of this difference in feeding-value may be due to change in botanical composition, particularly to increase in clovers, is entirely probable.

TEST III. *The Effect of Fertilization on the Quality of Protein in Pasture Grass*

In view of the marked differences in feeding-value of fertilized and unfertilized pasture herbage, found in the previous experiment, it was planned in this trial to test the possibility that quality of protein was a factor involved in these observed differences.

Results reported by Miller and Chibnall [4], and by Evans [5], suggest that perhaps pasture grass is deficient in cystine. From an amino-acid analysis of timothy, conducted in this Institution, Dyck and McKibbin [6] reported a notably low cystine-content. It was decided, therefore, to test the effect of adding purified cystine to the basal diets of both fertilized and unfertilized mixed-pasture herbage. Cystine was included in the rations of Lots III and IV at the rate of 0·4 per cent. This was equivalent to about 3 per cent. of the protein, and was the rate at which this amino acid was included, and found to give satisfactory results, in experimental diets reported by Mitchell and Smuts [7].

A mixed amino-acid supplement was also included in this test, for which purpose casein fortified with cystine was used. The cystine was added to the casein at the rate of 2·6 per cent. The cystine-fortified casein constituted 5·13 per cent. of the diets of Lots V and VI. Assuming the five essential amino acids (lysine, tryptophane, cystine, histidine, tyrosine) to represent 20·1 per cent. of the casein [8], the adjustment was equivalent to substituting the basic diet with a 1·14 per cent. mixture of these five amino acids.

Rations used.—The detail of the rations fed to each lot, including chemical composition, was given previously [1, p. 347]. Reference to Table 7 of that paper shows that a mixture of equal parts of oat-hulls and sugar was used to adjust the protein-level of the several diets approximately to that of Lot II (unfertilized grass plus salt). With the addition of the 5 per cent. casein in Lots V and VI, a rather large allowance of this mixture was necessary to maintain the protein-level wanted, with the result that the nitrogen-free extract was somewhat above, and the fibre somewhat below those of the other lots. This may partly explain the more rapid growth made on these latter diets. It will be noted also that, based on relative requirements for larger animals, there did not appear to be a deficiency of minerals (Ca or P) in any of these diets.

Rations.—The source and preparation of the herbage used as the basis of these rations have already been described (p. 332). The feed-consumption in this experiment was controlled, the amounts allowed daily per rabbit being approximately 80 per cent. of what previous trials had indicated to constitute full feeding. For the first seven days this allowance was 100 gm. of air-dry feed. For the next fourteen days

this was increased to 125 gm. During the last period it was necessary, owing to an error in a shipment of cystine, to reduce the feed-allowance to 115 gm. per rabbit per day. This reduction during the last period is clearly reflected in the growth curve. A twenty-eight day feeding period was used in this test.

Animals used and allotment.—Thirty eleven-week-old rabbits, obtained from the regular breeding unit, were used in this experiment. They were allotted to six groups, weight, sex, and condition being mainly considered.

Observations.—Marked differences in the response of the animals to the different treatments were evident immediately after the trial had started. The animals in Series A (Lots I, III, V) showed no loss in condition and continued to grow fairly rapidly. Those in Lot V, receiving the mixed amino-acid supplement, showed a considerable improvement over the other two lots. The cystine-addition in Lot III produced no noticeable immediate effect over Lot I.

In Series B more pronounced differences occurred. The animals receiving the straight unfertilized grass diet (Lot II), and those receiving the addition of cystine (Lot IV), lost condition, the loss in the first period being less severe for Lot IV, receiving the cystine, than for Lot II.

The addition of the mixed supplement in Lot VI resulted in a marked improvement over the other lots of this Series. These animals, with the exception of one, compared favourably with those receiving the fertilized grass plus the same supplement (Lot V).

Nine days after the experiment had started one animal in Lot II died. This rabbit was in an extremely emaciated condition. No abnormalities were found on post-mortem examination; consequently it seems that death was due to the unsatisfactory diet.

During the remainder of the experimental period there was no noticeable difference between Lots I and III. These animals were in good condition throughout the experiment and made fairly rapid growth.

Lots V and VI, receiving the mixed supplement, were in excellent condition and grew rapidly; they showed a greater liking for their diets than did the other animals, cleaning up their allotted quantities of feed more rapidly and always seeming hungry. One animal (No. 30 in Lot VI) was an exception so far as gains and condition were concerned. At the start of the experiment it was one of the largest animals in the lot. The bulky diet, however, seemed to be unsatisfactory, as it showed little or no change in weight during the trial. Post-mortem examination showed this rabbit to be definitely abnormal. The pyloric opening of the stomach was partially blocked, causing the accumulation of a packed mass of material in the stomach that could not pass through into the intestine. The data from this animal, therefore, were discarded in the analysis of the trial.

In Lot IV the beneficial effect of the added cystine became less pronounced towards the end of the experiment. The animals in Lot II lost condition rapidly at first, and although their general condition did not improve, some gains in weight were later recorded. The animals in Lot IV did not become poor and emaciated as rapidly as those in

Lot II, but at the close of the experiment their condition was not greatly different from the animals receiving no supplement.

The data.—The details of the initial weights and gains together with the statistical analysis of the gains are given in Appendix, Table 3. For purposes of statistical analysis, the gains for rabbit No. 17 (Lot II), which died on the ninth day of the experiment, and those for rabbit No. 30 (Lot VI) found abnormal on post-mortem examination after the trial, were estimated according to the method of Yates [4]. The mean lot gains are shown in the table following:

TABLE 3. *Effect of Fertilization on Quality of Protein in Pasture Grass (mean gains)*

Lot I	*Lot II*	*Lot III*	*Lot IV*	*Lot V*	*Lot VI*
Fertilized grass	Unfertilized grass	Fertilized grass + cystine	Unfertilized grass + cystine	Fertilized grass + cystine + casein	Unfertilized grass + cystine + casein
321	25	370	70	643	553

Analysis indicated that the difference between the mean gains of the animals on fertilized herbage (Lot I) and those on unfertilized herbage (Lot II) is highly significant. The increase in mean gains of Lots III and IV over Lots I and II, respectively, as a result of the addition of cystine, however, is not significant. The addition of the mixed supplement in Lots V and VI resulted in a highly significant increase over Lots I and III and II and IV, respectively. The difference between Lots V and VI is not significant.

Summary of Results and Discussion

Fertilized v. *unfertilized herbage* (Lots I and II).—The results of this comparison support those of the previous trial, namely, that some factor or factors other than quantitative differences in total protein, energy value, fibre or minerals (Ca and P) of the rations must be responsible for the difference in their nutritive value. The chemical analyses of the diets of these two lots show no appreciable difference excepting for phosphorus. That the animals in Lot VI made highly satisfactory gains on a diet still lower in P (than that of ration of Lots I and II) is evidence that this element was not a limiting factor in this comparison.

Addition of cystine (Lots III and IV). The failure of the addition of cystine to increase significantly the nutritive value of the herbage in either series is evidence that, in the case of these pastures, cystine is not deficient, or that still other amino acids are involved with cystine in limiting the feeding-value of the herbage.

It will also be noted that cystine supplements did not alter the relative standing of the fertilized and the unfertilized grass.

Addition of cystine plus casein (Lots V and VI).—The marked increase in the growth of the rabbits as a result of the addition to their diets of the mixed amino-acid supplement is the important feature of this

experiment. It is possible, of course, that a part of this increase was due to the slightly higher content of nitrogen-free extract in these diets. This theory, however, fails entirely to account for the relatively greater increase in the unfertilized-grass as compared with the fertilized-grass diet.

When this supplement was added the difference in the nutritive values of the diets containing fertilized and unfertilized grass disappeared. It seemed evident that the addition of the mixture of the essential amino acids was responsible for this result.

It would seem, therefore, (1) that the explanation of the differences in nutritive value of the herbage from fertilized versus unfertilized pasture lies partly in their amino-acid make-up, and (2) that in the herbage from these pastures cystine alone is not the limiting factor in their nutritive value.

It is fully realized that much further work will be necessary before definite conclusions can safely be drawn. However, all three tests herein reported have been quite clear cut, and it would seem, therefore, that the findings might be used to formulate a tentative working hypothesis around which to build further studies.

The first test points strongly to the idea that different species of grasses may be markedly different in their nutritive value, even though a routine feeding-stuffs analysis does not indicate such a difference.

The second and third tests suggest that at least a part of such differences, in mixed pasture-herbage, may be traced to the protein-complex. Here, of course, there may be involved several factors that are not separately measurable in these tests. For example, it is quite possible that the preparation of the feed (i.e. grinding and mixing), which prevented the counterpart of selective grazing, may have influenced the results, especially in the case of the herbage from the untreated pasture. Observation of grazing animals has shown that there is much less tendency for selective grazing on fertilized than on unfertilized pastures. Does it follow, then, that if selection is prevented, as in these tests, we are diluting the nutritious grasses with certain others of low feeding-value, thus lowering the value of the whole diet? And hence that the effect of fertilization is more a change in botanical composition of the mixture than of change, perhaps of protein-quality, within a species?

If this be the case, then it must require but a small change to produce wide differences, as is evident from the botanical composition of the mixture fed in these tests [1, Table 6, p. 345]. The chief change noted in the above-mentioned table is that of clover replacing weeds. Will other changes in botanical composition give the same difference in feeding-value? Obviously that can be determined only by a knowledge of the nutritive properties of the pure species, studies of which are now under way as a part of this investigation.

Then there are doubtless those who would question results obtained with rabbits in so far as their applicability to farm live stock is concerned. This problem urgently needs attention, for, while not thus far shown, it may nevertheless be found that the rabbit may have a peculiarly high requirement for some nutritional substance, as, for example, the

guinea-pig for vitamin C, which does not hold for cattle or sheep. These tests are reported, therefore, not only for the comparative data which they have yielded, but also in the hope that they may stimulate similar studies by other stations from which more information on the possible usefulness of rabbits in comparative feeding studies of diets for farm ruminants may be obtained.

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APPENDIX

TABLE I. *Timothy* v. *Reed Canary-Grass. Initial Weight, Feed Eaten, and Gains (expressed in grams)*

Lot I				*Lot II*				*Lot III*				*Lot IV*				*Lot V*			
Reed canary-grass 100 %				Timothy 100 %				Reed canary-grass 95 %, Lactalbumin . . 5 %				Timothy . . 95 %, Lactalbumin. 5 %				Alfalfa meal . 50 %, Oats . . . 40 %, Linseed meal 10 %			
Rabbit no.	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*
6	1,430	8,160	385	7	1,385	8,430	760	31	1,375	7,810	460	12	1,500	8,005	820	11	1,750	10,285	1,355
5	1,425	8,330	105	33	1,385	7,605	670	15	1,450	7,430	165	32	1,450	8,120	735	17	1,525	7,750	935
13	1,340	7,150	210	14	1,275	8,060	620	8	1,275	7,560	300	10	1,335	7,570	685	3	1,500	9,675	1,365
27	1,200	8,220	340	24	1,250	7,715	540	4	1,275	8,950	545	9	1,330	7,585	830	26	1,475	9,960	1,525
1	1,350	8,135	225	23	1,250	8,305	735	16	1,450	7,645	235	19	1,225	7,965	1,000	21	1,425	10,200	1,615
Av.	1,349	7,999	273	..	1,309	8,023	665	..	1,365	7,879	341	..	1,368	7,849	814	..	1,535	9,574	1,359
Mean gains adjusted for differences in initial weights and feed intake . .			287·56	..	..	..	641·14	..	..	..	389·78	..	..	..	870·58	..	..	..	1,262·87

Note: Initial weights are those of test-period proper. Initial weights at beginning of preliminary period are shown in table of allotment data.

Statistical analysis by variance yields the following results:

Standard error ($D/F^* = 13$) = 87·24 gm.

Standard error of lot means = $87{\cdot}24/\sqrt{5} = 39{\cdot}01$ gm.

Necessary difference between means of five ($P = 0{\cdot}05$) = $39{\cdot}01 \times \sqrt{2} \times t\,(n=13) = 119{\cdot}15$.

* Three degrees of freedom for error lost through calculation from the data of two regression values (initial weight on gain and feed on gain) and one missing value.

TABLE 2. *Fertilized* v. *Unfertilized Pasture Grass. Initial Weights, Feed Eaten, and Gains (expressed in grams)*

Lot I Fertilized grass 100%				Lot II Unfertilized grass 100%			
Rabbit no.	*Initial weight*	*Total feed*	*Gains*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gains*
1	920	2,775	305	2	960	2,620	−245
3	910	2,765	250	4	855	2,985	−55
5	785	2,900	330	6	760	2,545	65
7	635	1,985	160	12	500	1,810	15
Av.	812·5	2,606·25	261·25	..	768·75	2,490	−55

Statistical analysis yields the following results:

Standard error (D/F = 3) = 120·2 gm.
Standard error of lot means = 120·2/$\sqrt{4}$ = 60·1 gm.
Necessary difference between lot means $P = 0{\cdot}05 = 60{\cdot}1 \times \sqrt{2} \times t\ (n=3) = 270{\cdot}4$.

TABLE 3. *Effect of Fertilization on the Quality of Protein in Pasture Grass. Initial Weight, Feed Eaten, and Gains (expressed in grams)*

Lot I	%	*Lot II*	%	*Lot III*	%	*Lot IV*	%	*Lot V*	%	*Lot VI*	%
Fertilized grass	92·6	Unfertilized grass	99	Fertilized grass	90·0	Unfertilized grass	96·0	Fertilized grass	55·50	Unfertilized grass	59·50
Oat-hulls	32·2	Salt	1	Cystine	0·4	Cystine	0·4	Casein	5·00	Casein	5·00
Sucrose	3·2			Oat-hulls	4·3	Oat-hulls	1·3	Cystine	0·13	Cystine	0·13
Salt	1·0			Sucrose	4·3	Sucrose	1·3	Oat-hulls	19·19	Oat-hulls	17·19
				Salt	1·0	Salt	1·0	Sucrose	19·18	Sucrose	17·18
								Salt	1·00	Salt	1·00

Rabbit no. (Lot I)	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.* (Lot II)	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.* (Lot III)	*Initial weight*	*Total feed*	*Gain*
1	1,615	3,255	300	2	1,550	3,255	190	11	1,610	3,255	315
18	1,450	3,255	310	16	1,435	3,255	−335	32	1,575	3,255	480
19	1,355	3,255	245	17	1,215	3,255	15*	31	1,300	3,255	290
4	1,300	3,255	400	21	1,305	3,255	30	12	1,300	3,255	240
10	1,160	3,255	350	27	1,090	3,255	225	14	1,090	3,255	525
Av.	1,376	3,255	321	..	1,319	3,255	25	..	1,375	3,255	370

Rabbit no. (Lot IV)	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.* (Lot V)	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.* (Lot VI)	*Initial weight*	*Total feed*	*Gain*
28	1,455	3,255	30	29	1,635	3,255	625	30	1,635	3,255	560*
8	1,475	3,255	−110	6	1,450	3,255	645	7	1,450	3,255	545
5	1,340	3,255	145	20	1,330	3,255	655	3	1,315	3,255	570
26	1,300	3,255	40	13	1,440	3,255	520	9	1,300	3,255	455
22	1,195	3,255	245	23	1,225	3,255	770	24	1,210	3,255	635
..	1,353	3,255	70	..	1,416	3,255	643	..	1,382	3,255	553

* Calculated.

Note: Initial weights shown are for test-period proper. Initial weights for preliminary period are shown in table of allotment data.

Statistical analysis by variance method yields the following results:

Standard error ($D/F\dagger = 18$) = 116·73 gm.

Standard error of lot means = $116{\cdot}73/\sqrt{5} = 52{\cdot}205$ gm.

Necessary difference between means of five to cover experimental error ($P = 0{\cdot}05$)

$= 52{\cdot}205 \times \sqrt{2} \times t\,(n = 18) = 148{\cdot}38$.

† Two degrees of freedom lost through calculation of missing values.

THE COMPARATIVE DIGESTIBILITY OF ARTIFICIALLY-DRIED PASTURE HERBAGE BY SHEEP AND RABBITS

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WITH a view to simplifying and reducing the work and expense involved in digestibility trials, with special reference to pasture, consideration was given to the possibility of using rabbits in the place of ruminants, e.g. sheep or steers. Very little information appears to be available in the literature as to the digestive powers of rabbits, particularly in comparison with those of other species. Some early contributions were made to this subject by von Knieriem [2] and Weiske [3]. They determined the digestibility of cereals and feeding-cakes when fed alone to rabbits, and compared these results with those obtained by feeding the same materials, superimposed in a fodder ration, to sheep. Weiske, in one case, also fed oats alone to sheep and compared these results with those obtained with rabbits. The results in these cases indicated that the digestibilities were of the same order when determined with rabbits and with sheep. Von Knieriem [1] did determine the coefficients of digestibility of a number of species of clovers and grasses with rabbits, but, unfortunately, carried out no simultaneous comparison with ruminants. In view of work in progress and projected at Ottawa for a study of the nutritive value of pasture herbage, it was decided to carry out a comparative investigation on such material with a view to obtaining information as to the possibility of simplifying this investigation. Accordingly the tests with rabbits and sheep reported in this paper were carried out at the Rowett Research Institute.

Experimental

The material used for these studies was an artificially-dried pasture herbage, consisting of mixed grasses with some clover. It was cut in August 1934, when five weeks old, and dried in a band-drier.

The experimental animals consisted of four male rabbits and two wether sheep. Their ages, weights, breeds, and daily rations are given in Table 1.

The quantities fed were such as were readily and easily consumed by the animals. There was no refused feed. Rabbit 4, however, on several occasions during the first trial scattered his food on the floor of the metabolism cage. This was weighed and analysed and the necessary corrections made, but it was felt advisable to carry out a second trial. In the case of the remaining animals some scattering of the ration was unavoidable, but, as will be seen in Table 2, the quantities were negligible. They were, nevertheless, taken into account in calculating the coefficients of digestibility.

TABLE 1. *Experimental Animals and Daily Rations*

Animal	*Age in months*	*Weight* (kg.)	*Breed*	*Daily Ration of Herbage* (gm.)	
				Trial 1	*Trial 2*
Rabbit 1	9	2·32	English	125	. .
,, 2	9	1·87	Silver Dutch	125	. .
,, 3	9	2·09	Chocolate Havana	150	125
,, 4	9	2·20	English	150	125
Sheep 1	11	30·8	Orkney cross	700	. .
,, 2	11	30·2	Orkney cross	700	. .

TABLE 2. *Feed-Residues in Digestion Trials expressed as Percentage of Total Ration on Dry-Matter Basis*

Animal	*Residues (per cent.)*	
	Trial 1	*Trial 2*
Rabbit 1	0·67	. .
,, 2	0·74	. .
,, 3	0·31	0·51
,, 4	11·43	2·71
Sheep 1	1·40	. .
,, 2	0·61	. .

Preceding each trial, the hay was sampled and the necessary number of daily rations weighed out. The trial itself was divided into a preliminary period of ten days and a collection-period of twelve days. The collection-period was further divided into three equal sub-periods during each of which a composite sample of the faeces was prepared and analysed.

The necessary data for calculating the coefficients of digestibility are presented in Tables 4, 5, 6, and 7 in the Appendix, whilst a summary of the coefficients of digestibility is given in Table 3.

Discussion of Results

From the data given in Table 3 it will be observed that the total digestibility of the pasture herbage, as indicated by the organic-matter value, was much lower with the rabbits than with the sheep. The explanation for this seems to rest largely in the fact that the rabbits were unable to make very efficient use of the crude-fibre fraction. The average coefficient of digestibility for this constituent was 26·0 with the rabbits whereas the coefficient determined with sheep was 74·5. The rabbits also showed an appreciably lower digestibility-coefficient for the N-free extractives.

The crude protein was quite well digested by the rabbits, though the average coefficient was somewhat lower than that with sheep. It must be borne in mind, of course, that the relatively large amount of undigested crude fibre in the digestive tract of the rabbit probably caused an increase

TABLE 3. *Coefficients of Digestibility of Pasture Herbage Determined with Sheep and Rabbits*

Animal	*Dry matter*	*Organic matter*	*Nitrogen*	*Ether-extract*	*Crude fibre*	*N-free extract*
	%	%	%	%	%	%
Trial 1						
Rabbit 1	49·4	49·3	60·9	23·9	28·7	56·2
,, 2	49·8	49·5	64·3	21·5	27·0	56·6
,, 3	45·6	45·1	58·4	21·9	21·3	53·2
,, 4	48·1	48·0	60·8	22·8	26·1	55·7
Trial 2						
Rabbit 3	49·0	48·9	61·5	32·0	25·2	56·0
,, 4	50·9	50·9	63·1	32·9	27·6	57·9
Aver. for rabbits	48·8	48·6	61·5	25·8	26·0	55·9
Sheep 1	74·3	77·0	76·9	51·3	73·5	81·3
Sheep 2	74·3	77·3	76·4	52·2	75·5	81·4
Aver. for sheep	74·3	77·2	76·7	51·8	74·5	81·4

in the percentage of metabolic faecal nitrogen. Further, this fibre may have protected some otherwise digestible protein from the processes of absorption. It should not be concluded, therefore, from the data that the rabbits have less ability than the sheep to digest the proteins *per se* of the pasture herbage.

The coefficients of digestibility of the ether-extract were probably also influenced by metabolic products in the faeces. They were lower with the rabbits than with the sheep.

In general, it may be stated that, as indicated by the results with sheep, this artificially-dried pasture herbage was a highly digestible feeding-stuff. The rabbits, however, did not digest the crude fibre very readily. Largely at least, in consequence of this, the total digestibility of the herbage with this species was low in comparison with sheep. These results indicate quite clearly that in any study of the nutritive value of pasture as measured by its digestibility, it is not safe to use rabbits as experimental animals in place of sheep.

Summary and Conclusions

Digestibility trials were conducted with four rabbits and two sheep on an artificially-dried pasture herbage of five-weeks' growth.

The rabbits did not digest this herbage as well as the sheep. An important contributory cause of this was the inability of the rabbits to make efficient use of the crude-fibre fraction.

One of us (C.J.W.) desires to acknowledge his indebtedness to the Director, Sir John Orr, and Governors of the Rowett Research Institute for permission to work there for three months.

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APPENDIX

TABLE 4. *Composition of Artificially-dried Pasture Herbage*

(Dry-matter basis)

	Moisture	*Ash*	*Protein* (N × 6·25)	*Ether-extract*	*Crude fibre*	*N-free extract*
	%	%	%	%	%	%
Trial 1	10·05	9·37	20·76	5·15	21·56	43·16
Trial 2	9·07	9·27	20·93	5·11	21·33	43·36

TABLE 5. *Calculation of Coefficients of Digestibility of Rabbits in Trial 1*

(Weights in grams. Collection-period 12 days)

	Dry matter	*Organic matter*	*Nitrogen*	*Ether-* ~~*fibre*~~	*Crude fibre*	*N-free extract*
Rabbit 1						
In feed . .	1,340	1,214	44·5	69·0	289	578
In faeces . .	678	616	17·4	52·5	206	253
Digested . .	662	598	27·1	16·5	83	325
Coefficients % .	49·4	49·3	60·9	23·9	28·7	56·2
Rabbit 2						
In feed . .	1,339	1,213	44·5	69·0	289	578
In faeces . .	672	613	15·9	54·2	211	251
Digested . .	667	600	28·6	14·8	78	327
Coefficients % .	49·8	49·5	64·3	21·5	27·0	56·6
Rabbit 3						
In feed . .	1,614	1,462	53·6	83·1	348	697
In faeces . .	878	802	22·3	64·9	274	326
Digested . .	736	660	31·3	18·2	74	371
Coefficients % .	45·6	45·1	58·4	21·9	21·3	53·2
Rabbit 4						
In feed . .	1,434	1,302	47·2	74·1	314	619
In faeces . .	744	677	18·5	57·2	232	274
Digested . .	690	625	28·7	16·9	82	345
Coefficients % .	48·1	48·0	60·8	22·8	26·1	55·7

TABLE 6. *Calculation of Coefficients of Digestibility with Rabbits. Trial 2.*

(Weights in grams. Collection-period 12 days)

	Dry matter	*Organic matter*	*Nitrogen*	*Ether-extract*	*Crude fibre*	*N-free extract*
Rabbit 3						
In feed . .	1,357	1,231	45·4	69·3	290	588
In faeces . .	692	629	17·5	47·1	217	259
Digested . .	665	602	27·9	22·2	73	329
Coefficients % .	49·0	48·9	61·5	32·0	25·2	56·0
Rabbit 4						
In feed . .	1,327	1,204	44·4	67·8	283	575
In faeces . .	651	591	16·4	45·5	205	241
Digested . .	676	613	28·0	22·3	78	334
Coefficients % .	50·9	50·9	63·1	32·9	27·6	57·9

TABLE 7. *Calculation of Coefficients of Digestibility with Sheep.*

(Weights in grams. Collection-period 12 days)

	Dry matter	*Organic matter*	*Nitrogen*	*Ether-extract*	*Crude fibre*	*N-free extract*
Sheep 1						
In feed . .	7,450	6,751	247	384	1,606	3,216
In faeces . .	1,913	1,555	57	187	426	601
Digested . .	5,537	5,196	190	197	1,180	2,615
Coefficients % .	74·3	77·0	76·9	51·3	73·5	81·3
Sheep 2						
In feed . .	7,513	6,808	250	387	1,619	3,243
In faeces . .	1,930	1,545	59	185	397	604
Digested . .	5,583	5,263	191	202	1,222	2,639
Coefficients % .	74·3	77·3	76·4	52·2	75·5	81·4

THE ROOT-SYSTEM OF THE SUGAR-CANE

Pt. I. METHODS OF STUDY

H. EVANS

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With Plate 19

Introduction.—This journal has recently contained a series of very interesting contributions by Nutman on the root-system of *Coffea arabica* [1, 2], and it is thought that a description of the investigations on the root-system of different varieties of sugar-cane, carried out during the last three years in Mauritius, will provide an interesting comparison of the methods used and the problems to be solved in the case of two such widely differing crops as sugar-cane and coffee.

For those who are unfamiliar with the agriculture of the sugar-cane, it may be stated that the planting material (except new seedling varieties, which are grown from seed) consists of the top part of the stem, generally known as 'setts'. These setts bear rings of small dots or root-primordia just above the nodes, and at the nodes bear the buds. Two, or sometimes three, such setts are planted in holes about 6 in. deep and covered with a light layer of soil. On germination, the root-primordia develop giving rise to the 'sett-roots', and the buds sprout giving rise to the young shoots. The crop eventually obtained is called the virgin, or plant crop; in Java it is the only one reaped, the field being afterwards uprooted, but in Mauritius and in several other sugar-producing countries the stools sprout again after the virgin crop has been harvested, and give rise to a succession of ratoon-crops. Usually five or six such ratoon-crops are reaped before the field is uprooted and a virgin crop again planted.

The study of the root-system of a fast-growing crop like sugar-cane presents a multitude of problems for elucidation. The most important aspects of the subject may be summarized as follows:

1. The development of the root-system of the virgin crop from the cutting to maturity. This involves studies in the 'germination' of the cuttings; the nature, spacial distribution, and quantity of roots with age.
2. The development and nature of the root-system of ratoon-crops.
3. A survey of the root-systems of different varieties of cane. Varietal differences in the root-system are of great importance in selecting canes for particular conditions.
4. The effects of soil and of external factors in general on the nature and the distribution of roots.
5. The nature of the individual roots; formation and length of life of root-hairs; changes in the roots with age.
6. The function of the various types of roots; physiological activity in different layers; depths to which the roots absorb water and mineral salts.
7. The effects of cultivation and of fertilizer applications on root-development; possible tropic responses.

More or less bound up in these main aspects are such problems as the relationship between the root-system and aerial development and the resistance of root-systems to insect pests and to diseases in general. Resistance to insect pests is of considerable importance in Mauritius, where large areas suffer severely from the depredations of the root-eating larvae of the beetle *Phytalus smithi*, Arrow. Fundamental research on sugar-cane root-systems is of great importance for the elucidation of problems connected with the time and method of application of fertilizers; the time and value of various cultural practices; the proper distribution of varieties on the basis of their suitability for dry or waterlogged conditions; resistance to cyclones, which are common in the colony; and other problems of greater or less moment.

A review of the most important investigations carried out elsewhere on the root-system of sugar-cane has recently been published (see Bulletin No. 6, Sugar-cane Research Station, Mauritius), and it is not proposed to review previous investigations here.

Methods and Procedure

Several methods have been used for the study of certain aspects of the root-habits of sugar-cane. As some of these methods may prove of value to other investigators in this field it is proposed to describe them in some detail.

I. *Early Stages*

For the study of the 'germination' stages, i.e. from the time of planting the sett to about 3 months of age, two principal methods have been used: (*a*) the quantitative method of weighing the sett-roots and the shoot-roots (i.e. those roots arising from the young shoots as contrasted with the sett-roots originating from the sett) at intervals, accompanied by microscopic examination to determine the density of root-hairs, degree of branching, &c.; (*b*) planting the setts in specially made root-boxes containing the soil layers in the same order as they occur naturally in the field. The boxes have detachable sides, and the main framework of the box bears sheets of wire-netting in the horizontal and vertical planes. At the time of examination the sides of the box are removed and the soil washed away with a jet of water leaving the roots suspended in the netting. The root-system is then carefully examined. This method is, in essentials, similar to that used by Venkatraman in India, as subsequently modified by Hawaiian workers [3, *et seq.*].

II. *Development of the Root-system and Study of Mature Root-systems*

For the study of root-systems at various ages from 3 months to maturity, and for the survey of the varietal distribution of roots, three chief methods have been used:

(*a*) *The 'direct-examination' method of Weaver*.—This method involves digging a trench at a distance of about 8–10 in. from the stool, and as a rule long enough to include 4–5 stools. The trench is dug in the first instance to a depth of about 4 ft. and roots are laid bare, starting from the stool out-

wards. The position and course taken by every root in a specified thickness of soil (6 in.) is mapped to scale on graph paper, and in following the roots downwards the trench is deepened. In some cases it was necessary to dig the trench to a depth of 20 ft. to follow the deep roots to their termination. A chart showing the root-system in section is thus obtained, but generally a section in two directions at right-angles was taken, as it has been shown that the root-system is not always symmetrical.

(*b*) *The 'block' method.*—The author first saw this method used by W. S. Rogers at East Malling Research Station in a study of the root-system of fruit trees. Owing to the extreme thinness of sugar-cane roots as compared with the relatively thick roots forming the framework of the root-system of fruit trees, it was necessary to modify the method as previously used. The method involves the determination of the position in space of every root, and the subsequent reconstruction of the root-system in a specially-made frame. A rough indication of the spread of roots is first obtained, and a square trench is dug enclosing an area, the magnitude of which depends upon the spread of roots. This area is divided into four quarters which are termed *A*, *B*, *C*, and *D*, and each quarter is subsequently subdivided into smaller squares with 1-ft. sides. Each little square may be designated *Aa*, *Ab*, &c., to indicate its position in the large square *A*, or *Ba*, *Bb*, &c., its position in the large square *B*. By means of a variety of instruments, such as little hand-picks, trowels, prospector's picks, &c., each root in one of the small squares is laid bare to a depth of 6 in. The direction and position of each root is marked to scale on a chart, and records of the depths of the end nearer the stool and the end remote from the stool are taken for each root. The course of the roots in space is thus accurately known; each root is given a nomenclature, such as Aa_1, Bd_3, which is noted in the chart, and a label bearing this nomenclature is tied to it. Each square foot is dealt with thus to a depth of 6 in., until the whole root-system has been excavated to the same depth. The next 6 in. are then dealt with in the same way, and similarly the following layers, until the whole root-system has been excavated, charted, and labelled. A large frame of about $8 \times 8 \times 6$ ft. is then built with cross wires at intervals of 6 in. The root-system is reconstructed in this frame, each root being placed in its correct position. The reconstructed root-system, which is thus identical in position with that occupied in the soil, can be studied and photographed.

In the later investigations the method was modified in detail so that areas larger than 1 sq. ft. could be dealt with at a time; these areas, being narrow sectors reaching to the stool, made it unnecessary to cut the roots frequently and then tie them together afterwards. This is probably the best method that is likely to be worked out for the detailed investigation of the distribution of sugar-cane roots, not only because of the convincing reconstructed system obtained at the end of the work, but because of the wealth of detailed information derived in the actual excavation. It is, however, an extremely long and tedious method, and unless adequate funds and labour are available its execution is impracticable. For young root-systems, and for those which are very superficial, the method does not take so long, and has advantages over all other methods.

(*c*) *The 'successive-section' method.*—This method is intermediate between the 'direct-examination' method and the 'block' method. It involves working a trench to a depth of 1 ft. at a distance of about 8 ft. from the stool, the actual distance depending upon the length of the longest roots. The trench is sufficiently long to cover about 4 stools. The side of the trench nearest the stools is worked towards the stool for a few inches with hand-picks, and all the roots entering into the trench are marked to scale on graph paper. The trench is then widened to 2 ft. and deepened to 2 ft., and the roots emerging into the trench are again plotted. The trench is thus progressively widened by successive foot-widths, the depth being increased by 1 ft. for each 1 ft. increase in width. The diagrams (Fig. 1) explain the method used.

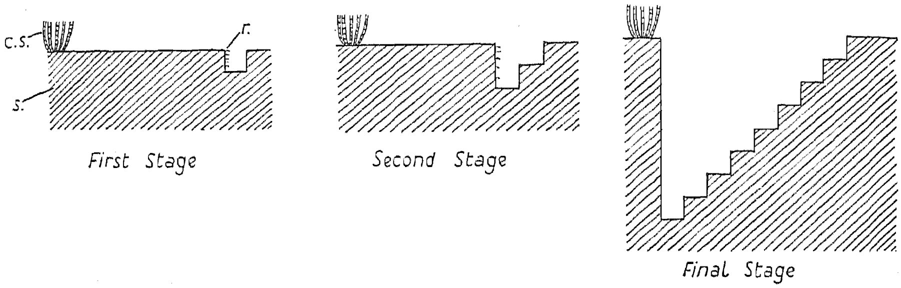

FIG. 1. Illustrating the Investigation of the Sugar-cane Root-system by the 'Successive Section' Method. *c.s.* = cane stool; *r.* = roots; *s.* = soil. Scale $\frac{1}{8}$ in. = 1 ft.

It will be seen that the final stage is equivalent to the section obtained in the direct examination method. If the roots penetrated more than 8 ft., the trench was deepened until the termination of the roots was reached. This method thus amounts to the examination of one-half of the complete root-system. It tends to have a quantitative value in that the number of roots at varying distances from the stool and at varying depths is obtained. From the charts a mental picture of one-half of the root-system may be constructed. The method, although not as detailed as the block method, gives considerably more information than the 'direct-examination' method.

III. *Special Methods*

For the study of particular problems connected with the root-habits of sugar-cane certain special methods have been used.

(*a*) *Study of individual root-growth, and changes in the roots with age.*—For the study of individual roots of different varieties and their behaviour special root-boxes were used. These root-boxes were large-scale editions of the boxes with glass sides that are used in elementary plant physiology for studying the growth of bean roots, contractile roots, &c. The boxes were strongly built and measured $3 \times 3 \times 3$ ft. One side was made of glass, placed at an angle of about 30° to the vertical, and marked in square centimetres. The roots grew against the glass and were marked daily to scale on graph paper, being in complete darkness except during the daily examination.

Owing to the unnatural conditions in such boxes, in later experiments canes were planted in the field, and a long trench was dug at a distance of 2 ft. from the stools. Glass plates marked in square centimetres were fixed on the side of the trench, and the roots were observed in the same manner as in the boxes. By inserting long glass tubes filled with various fertilizers well into the soil, alongside the glass, it was possible to determine whether the fertilizer had a chemotropic action or not. The time during which the roots bore root-hairs could also be determined, and also the daily growth in length of the roots. This method of observing the growth of roots has also been extensively used by Rogers at East Malling Research Station.

(*b*) *Study of the superficial roots of ratoon-crops.*—Since in the ratoon-crops only the roots in the first 8 in. of soil are markedly affected by manuring and cultivating operations, a special study of the roots in this layer was made and the effect of cultivation on root-growth determined. For this study, pegs were placed in the ground to hold the roots in their correct position, and the soil was removed by means of a water-jet. All the main roots in the inter-line and between the stools in the row were plotted to scale on graph paper, a distinction being made between the older roots and the new white roots.

(*c*) *Studies on the functions of sugar-cane roots.*—Considerable light has been thrown on the functions of the different types of sugar-cane roots by making use of the well-known phenomenon of root-exudation. Trenches were dug in the region previously occupied by the stools, the roots outside the trench being left undisturbed in the soil. The soil was removed from the cut ends of the roots for a distance of about 6 in., and the cut ends were washed with formalin and thereafter with distilled water. Tubes were placed to receive the liquid exuded by the cut ends of the roots, the latter being fixed in position by plugs of cotton-wool. The tubes were held by wire holders, the free ends of which were forced into the soil. By collecting and analysing liquid exuded by roots at various depths, considerable information on the absorbing capacity of the roots was obtained.

IV. *Nature of the Sugar-cane Root-system*

To understand the true nature of the mature root-system of the sugar-cane, it is necessary to trace briefly its development. As has been stated above, the root-primordia on the sett 'germinate' under favourable conditions and give rise to the 'sett-roots', which are thin, much-branched fibrous roots passing laterally outwards to a distance of 1½ to 2 ft. Following protrusion of the sett roots, the buds on the sett swell and sprout, giving rise to the young shoots. The root-primordia at the very base of the young shoot are much larger than those borne on the sett, and also much larger than those borne later on the young shoot. These large root-primordia 'germinate' to give rise to thick white roots, which Venkatraman [3] has called 'shoot-roots'. The shoot-roots in the main pass downwards into the subsoil, and are not so profusely branched as the sett-roots. As more and more nodes are laid down in the growth of the young shoot, more root-primordia germinate, those nearer the soil

surface giving rise to roots which generally pass laterally outwards and form the framework of the superficial root-system of the cane.

The sett-roots are temporary, they soon die and decay, and, in general, the number of sett-roots left by the time the cane is 3 months old is negligible. There is often a tendency for the roots to be influenced in their line of growth by the direction which the bud on the sett faced when planted. Setts also often show a marked polarity, the roots germinating first on the basal end of the cutting, and shoots at the apical end. Roots developed from primordia on that side of the cutting which happens to be uppermost often become aborted and shrivel up, whereas those borne on the underside of the cutting make vigorous growth. The sequence of root-development described for the young shoot borne on the cutting is followed later by the daughter shoots and 'babas' borne on the rhizomes. Each of these has its shoot-roots at the base, forming thinner roots from nodes higher up the stem. The term 'shoot-roots', which is useful to contrast these roots with sett-roots, loses its significance when the sett-roots are no longer present, and all the roots are shoot-roots. We have therefore termed these roots 'buttress-roots', for reasons which will be given later. Since each new shoot that appears in the stool bears its buttress-roots, new shoots being formed for considerable periods, and since these buttress-roots persist for several months, they form a characteristic feature of the sugar-cane root-system at all times. The superficial roots which are produced from primordia formed later are much thinner than the buttress-roots, and, as their name implies, are located for their whole length in the surface-soil. In addition to the superficial roots and the buttress-roots, there is a third class of roots which in many respects resembles superficial roots, but turn downwards and penetrate the soil often to very profound depths. These roots often become associated in the form of strands or ropes, and have therefore been termed 'rope-systems'. They do not appear to arise from any distinctive primordia in the stool, as do the buttress-roots.

During our investigations over 200 root-systems of sugar-cane belonging to over forty different varieties were investigated in detail, and as the three types of roots distinguished above were found to be present in varying degrees of development in all the sugar-cane varieties studied, they will now be described in detail.

1. *The superficial absorbing roots.*—As has been stated, these roots originate from root-primordia situated at some distance from the base of the rhizomes. As they pass outwards from the stool they often become even more superficial; arising at the stool at a depth of 6–9 in., they terminate as a rule only a few inches below the soil surface. When they are first formed they grow away vigorously from the stool and very seldom branch. At this time they are white in colour, sometimes tinged with pink. While the root is still growing, the older part of it near the stool becomes first yellow, then brown, and when growth is complete the brown colour progresses along the root to the tip. Prolific branching of the root occurs when the growth in length is complete. The branches are fibrous and at first white, later becoming brown like their parent root. The branches thereafter bear branches of the second order, which

rarely bear branches of the third order and hardly ever branches of higher order than the third. These branch-rootlets are very densely covered with root-hairs, the superficial roots thus exposing a much increased area for absorption.

The main roots become much darker with age and eventually are almost black. The old superficial roots show another interesting feature in that they often become ribbed, assuming an appearance similar to the shoots of switch plants. Sections showed that this ribbed appearance was due to the collapse of cortical cells at some points, the hypodermal layers thereafter caving in at these points. Even when this occurs the vascular cylinder still serves as a conducting channel from the living rootlets, borne towards the end of the root, to the remaining organs of the stool. The length of the superficial roots varies: maximum lengths of 12–14 ft. were recorded in the variety Uba, and generally the longer surface-roots are 6–8 ft.; there are also several roots 2–6 ft. long. These roots form the major part of the surface system. In addition to these, however, there is later a slight addition to the surface-system caused by the germination of root-primordia at or up to an inch below the soil surface. The part of the cane on which these root-primordia are borne resembles the sett, and the roots which are formed from these primordia in many respects resemble sett-roots. They are formed only when the stool is well grown and the root-system nearly mature. Owing to their superficial origin they can be formed only when the moisture conditions are particularly favourable. They remain superficial for the whole of their length, often being only a fraction of an inch below the soil surface, are generally very short (6–18 in.) and bear a large number of fibrous branches. Owing to the quick drying out of the surface soil ($\frac{1}{2}$–1 in.) in which they occur, together with occasional harmful temperatures, they do not bear many root-hairs, and that they are of little importance to the stool is shown by the fact that they do not exude any liquid even when moisture is abundant.

It has been shown that under moist conditions the main superficial system supplies the stool with large quantities of water and with most of its mineral substances, but under conditions of drought absorption by the superficial roots is rendered almost impossible, and in order to survive the stool has to rely on the deeper roots. Typical superficial roots are shown in Fig. 2 (Plate 19).

2. *The buttress-roots.*—These roots, though in spacial distribution midway between the superficial system and the system of deep roots, are generally the first to be formed on the developing shoots. In appearance and direction of growth they remind one of stilts, except that they are underground for the whole of their length. When young they are white and succulent, and grow at a faster rate than the superficial roots. They pass outwards and downwards at an angle of 45–60°, although occasionally a few pass vertically downwards. Thus they soon enter the subsoil, and they never radically change their direction of growth. When young and actively growing, they bear a profusion of root-hairs, but when mature, root-hairs are only present in a region just behind the wax-like tip. The root acquires an orange colour as it matures, which after

considerable time may deepen to brown, but it never reaches the depth of colour of the superficial roots. When growth is active, the white wax-like root tip may be 6 in. long, with a sharply tapering point. We have actually observed buttress-roots growing at a rate of 8 cm. in 24 hours. When growth ceases, the tip becomes blunt and rounded and the orange coloration of the older part progresses to the tip. The buttress-roots are often found to be considerably distorted and flattened in various planes, so that the longer width may be from 5 to 10 times the shorter width. There is little doubt that they adjust their growth in this way in passing through a dry subsoil: the distortion does not appear to be due to subsequent crushing of the roots, after they have developed, by the stresses in the soil. This is confirmed by sections showing a vascular cylinder surrounded by large succulent cortical cells, which are longer and more numerous in the longer diameter, but show no crushing. When the activity of longitudinal growth of the buttress-roots has abated somewhat, they, like the superficial roots, give off branches. These branches are longer and thicker than the branches borne by the superficial roots and more like their parent roots in appearance. In the subsoil, where these branches are produced, rocks are generally numerous in Mauritius, and one often finds these branches growing along the surface of the boulders. When this happens branching is greater, but the branches are still fairly thick and flattened and never have a fibrous appearance. Sometimes they pass through the soft crust of the rock. Buttress-roots grow to a length of 2–5 ft., depending upon the variety and the conditions of growth. They do not expose nearly so large a surface to the soil as do the superficial roots. It is obvious from their direction of growth, the nature of their branching, and their localization in the subsoil, which is poor in mineral nutrients, that in the main they are anchoring roots, though they undoubtedly absorb to some degree. They may also act to some degree as storage organs, since the large succulent cells of the cortex contain considerable quantities of sugars and other organic materials. Their average breaking stress is about 3 kg., a value which is about double that of the main superficial roots. Buttress-roots are shown in Fig. 3.

3. *The rope-system and other deep roots.*—It has been found impossible to correlate the type of roots included in this class with their point of origin in the stool. Sometimes they arise from horizontally-growing rhizomes, and sometimes from rhizomes which grow up more or less vertically and bear the aerial culms. Intermixed with them, as regards origin, are roots which grow laterally outwards and upwards and form the main superficial roots. There may be a physiological difference between them and the superficial roots which enables them to respond to gravity in the normal way. If so, this difference does not appear to be connected with their point of origin in the stool, nor with the nature of the primordia from which they arise. Once these roots penetrate the subsoil they become very different in external appearance from the superficial roots. They are thin, but white, grow vigorously when young, and the growing tip remains white when the older parts of the root darken to become eventually almost jet black. The older roots of this class are characterized by their thin, wiry, and dark appearance; they

bear very few branches when they follow an individual course through the subsoil; but most often they do not follow an individual course, several roots originating at points often widely distant from each other in the stool become associated and the whole group passes down together as an entity. There may be only four or five such roots in the strand near the stool, but lower down at depths of 5–6 ft. the strand may contain

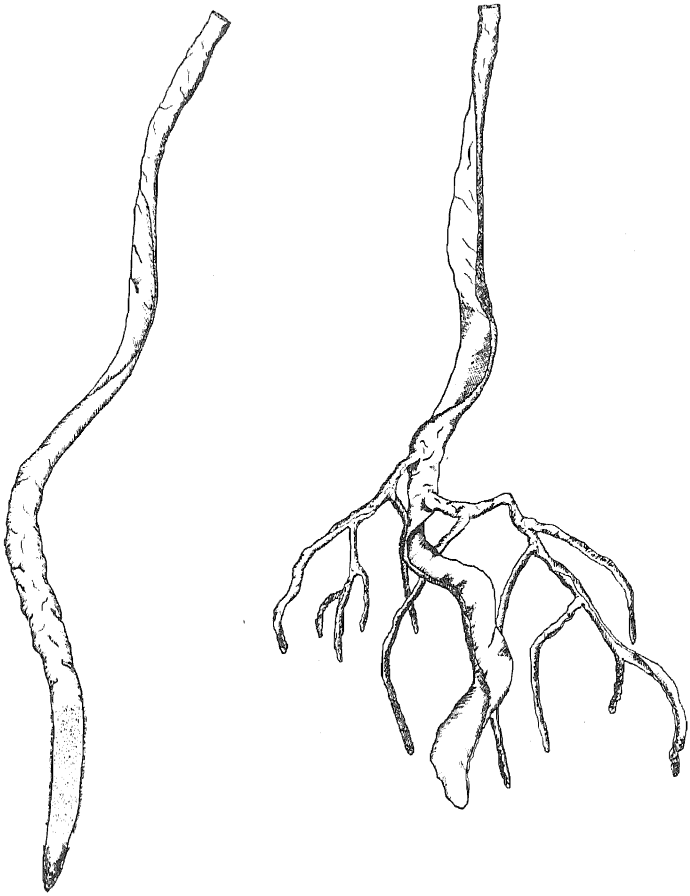

FIG. 3. Buttress-roots; on the left young unbranched root, on the right older branched root, showing distortions.

15–20 roots. The addition to the strand is sometimes due to individual roots of this class happening to grow into contact with a strand and thereafter following the same course. More often, however, it is due to roots in the strand branching to form secondaries of almost the same order of magnitude as the parent root, these branches thereafter entering into the strand entity. In addition to this type of branching, another type of branching occurs in the roots of the rope-system that leads to the formation of short roots about $\frac{1}{2}$–1 cm. in length. These short rootlets also bear root-hairs, and in practically all cases some of the main roots of the rope, when dug up, were found to be still white and growing at

the tips. The individual roots of the rope, as might be expected, do not all terminate at the same point. These rope-systems are much more strongly developed in canes having wild blood than in the noble tropical canes (*Saccharum officinarum*). In some cases, particularly Uba (*Saccharum sinense*), and seedlings of the cross POJ. 2878 × Uba Marot, they descend to depths of 15–20 ft. Rope-systems can withstand remarkably high stresses in their natural condition; a good one will support a weight of 12 kg. The remarkable behaviour of the roots in forming such rope-systems is difficult to understand, but the following explanation appears to be reasonable. The deep subsoils of Mauritius are poorly aerated, and when a channel is formed by a root, other roots follow this channel owing to the better aeration. With the inclusion of more roots, aeration is further improved. The little rootlets do not grow outwards because of lack of oxygen, and therefore curl round the parent roots of the rope. This is confirmed by the fact that when roots similar to those associated in ropes, follow an individual course through the deep subsoil they seldom bear any branches. There appears to be some repellent factor in the subsoil, which is most likely lack of oxygen but may be some other toxic factor. The latter possibility is supported by the fact that planters in general regard the subsoil of Mauritius as being particularly toxic, and for that reason do not resort to deep ploughing, the bringing of subsoil to the surface having been shown to depress yields. There is certainly a high concentration of alkali chlorides in the deeper subsoil. Although the rope-systems, whatever the cause of their peculiar growth, are so well suited for anchorage, they do not seem to be so important for this function as the superficial and, particularly, the buttress-roots. Varieties which have a poorly-developed superficial and buttress system are often blown down by high winds in spite of vigorous rope-system formation. Rope-systems are capable of very vigorous absorption, particularly because they descend to depths of soil which are moist even in times of extreme drought. Under such conditions the stool is dependent upon the deeper buttress-roots and rope-systems for its supply of water. A typical rope-system is shown in Fig. 4.

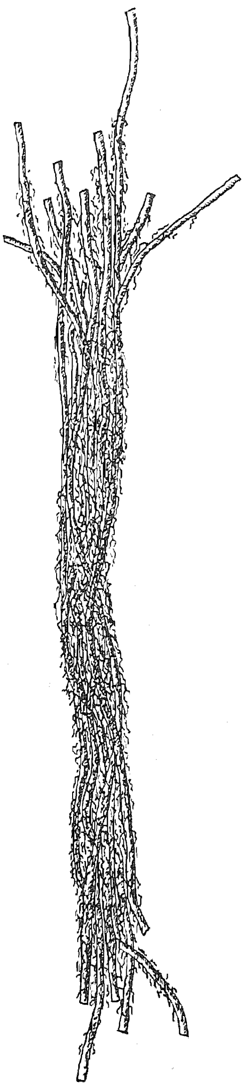

FIG. 4. Part of a Rope-system of Sugar-cane.

Summary

The root-system of the sugar-cane shows considerable variation, depending on the variety of cane, but in practically all varieties it is made

up in the main of three classes of roots; the superficial roots, the buttress-roots, and the deep roots mostly associated as rope-systems.

A good root-system is one which shows adequate development of each of the three root-types; relatively few of the cultivated varieties have such a system.

In most of the noble canes, the surface-system is well developed, and sometimes the buttress-system; but the rope-systems are very rudimentary. In some cases buttress- and rope-systems are adequately developed, but the superficial system is weak.

Fig. 5 gives a picture of the orientation of the root-types and some idea of the way in which they compose the mature root-system.

It is hoped to give a description of the more representative types of sugar-cane root-systems in a subsequent paper.

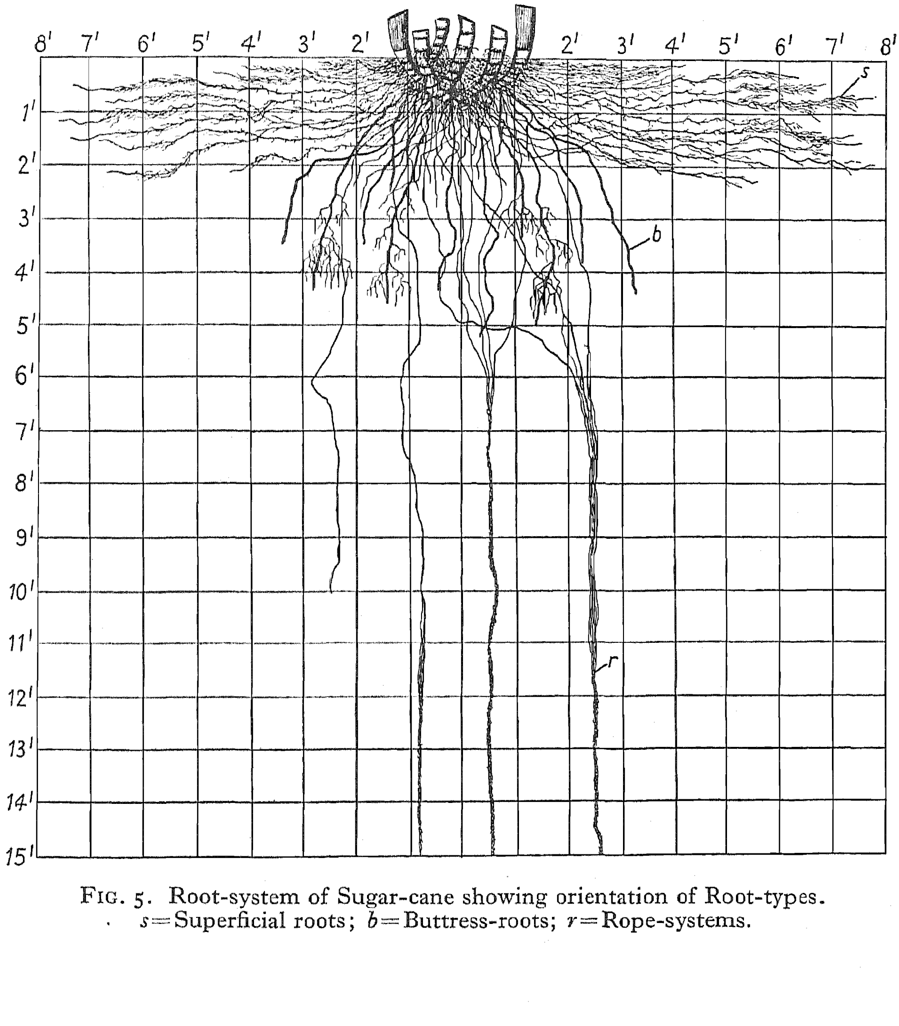

FIG. 5. Root-system of Sugar-cane showing orientation of Root-types. *s*=Superficial roots; *b*=Buttress-roots; *r*=Rope-systems.

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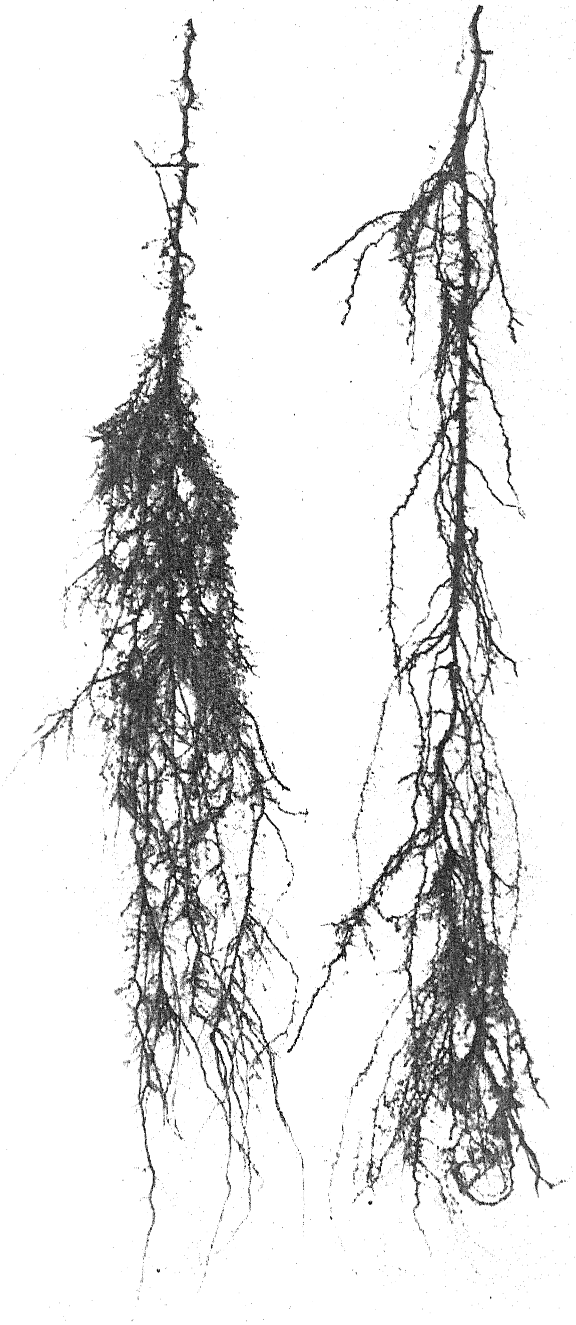

FIG. 2. Typical superficial roots of sugar-cane

MINERALS IN RELATION TO DISEASE OF THE LARGER DOMESTICATED ANIMALS

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Introductory.—The purpose of this article is to survey the more important disorders associated with metabolism of the mineral constituents of a ration, but in doing so it is impossible to avoid incidental reference to other constituents, such as vitamins, which may influence the utilization of dietary minerals, or to factors such as endocrine secretions which may affect the balance of minerals within the tissues of the animal itself. It is not always a straightforward matter to decide when a disease is due to simple mineral deficiency and when it is due to faulty operation of the physiological mechanisms for utilizing available minerals; and since the same pathological picture may result from apparently different causes, whilst different diseases may appear to arise from the same cause, it is best to consider the subject from the standpoint of animal physiology rather than from that of agricultural chemistry.

For example, the bone-disease rickets may arise in a grazing calf under a tropical sun as a result of phosphorus-deficiency in the pasture, but in a slum child arise from insufficient sunlight on a diet adequate in phosphorus—and then be curable by administration of cod-liver oil. The disease is the same in both cases but the cause is different. Conversely, if a cow and a horse be fed on a ration in which the roughage is cut down to a minimum and the concentrates unduly raised by a heavy supplement of cereals and bran, in such a way as to bring the ratio of calcium to phosphorus, expressed as $CaO : P_2O_5$, to about 1 : 3, the horse [1] will gradually develop 'osteodystrophia fibrosa' (osteofibrosis), a disorder histologically similar to Recklinghausen's Disease in man—a disease not usually associated with dietary régime at all but with tumours in the parathyroid glands. On a similar ration the cow may pass unscathed [2], but if the calcium-phosphorus ratio be widened still further skeletal disease also appears [3], but it is not osteofibrosis; it is osteoporosis, a pathologically different condition [1] which will be discussed presently.

In the progress towards the newer knowledge of nutrition built up over the last quarter of a century it is natural that the physiologist and the biochemist, working with synthetic diets and small laboratory animals in the spirit of pure scientific inquiry, should have led the way, and at first there was a natural tendency to assume that conclusions based upon experimental work on guinea-pigs and rats could be carried over to the economically important domesticated animals without further ado. But it was soon realized that each species of animal must be considered separately with reference to its own physiological peculiarities and its own mode of life. This is particularly noticeable with regard to exogenous requirements of vitamins, i.e. the quantities of the different known vitamins which must actually be present in the

food. Although the vitamin requirements of the bovine cannot be altogether ignored, young heifers have been brought from a live-weight of 300 lb. to a weight of 1,200 lb. [2] on a ration so low in all vitamins that it would induce scurvy in the guinea-pig (vitamin C), polyneuritis in the pigeon (vitamin B), xerophthalmia and nutritional failure (vitamin A) in the white rat, and rickets or osteomalacia (vitamin D) in any young animals insufficiently exposed to sunlight. The vitamin requirements of different farm animals vary considerably according to species and environmental conditions, but to continue discussion in that direction would go beyond the scope of the present paper. Suffice it for the moment to say that vitamin-deficiency diseases are less important in the larger animals than in man.

Returning to minerals, calcium and phosphorus may be considered together since both are involved in skeletal disorders. Magnesium, iron, copper, iodine, and fluorine may then be taken in order, with brief final reference to sodium, potassium, and chlorine.

Calcium and Phosphorus

At the outset two types of disease associated with calcium metabolism must be distinguished, one occurring as the result of deficiency of essential dietary constituents, and the other occurring as the result of failure of the animal to keep the minerals in its blood between healthy limits. The former may be termed 'aphosphorosis' (phosphorus-deficiency disease), or 'acalcicosis' (calcium-deficiency disease), or 'avitaminosis' (vitamin-deficiency disease) as the case may be, the word in each case signifying a cause. For low blood calcium the word 'hypocalcaemia' is used, and 'hypomineralaemia' would be a general word signifying low blood minerals without specifying any particular element or suggesting any particular cause.

Since considerable confusion exists in some quarters between low mineral-content of the blood and low mineral-content of the food, it should be explained that although the two may be related there is no necessary connexion at all. For example, if a maiden heifer is fed on a ration low both in phosphorus and in calcium, the inorganic phosphate of the blood plasma falls quite rapidly, and finally to a very low level, whilst the calcium tends to be arrested at a fairly definite lower physiological limit. After a year or so the plasma phosphate may have fallen from a normal of about 5 mg. p.c. (milligrams per 100 c.c.) even down to 1 mg. p.c., whereas the plasma calcium may have fallen only from 10 mg. p.c. to 8 mg. p.c.—a fall of 80 per cent. in one case and only 20 per cent. in the other. On the other hand, on a ration rich in both elements the blood calcium of a cow may drop quite unexpectedly from 10 mg. p.c. to 3 mg. p.c. within 24 hours of calving (milk fever) without noteworthy change in blood phosphorus.

The reason for this is that the level of plasma calcium is under the influence of a rigorous physiological controlling mechanism whilst the level of plasma phosphate is not—or at least not to the same extent. Hence although 'hypophosphataemia' is characteristic of phosphorus-

deficiency in the food, one cannot argue that 'hypocalcaemia' indicates calcium-deficiency.

In the case of calcium the physiological controlling mechanism is 'nervous endocrine' in nature, the word endocrine being used to refer to certain glandular structures which secrete active principles directly into the blood-stream and not through ducts. Such glands operate in association with the sympathetic nervous system and co-operate with the organs of storage, of absorption, and of excretion to form complex regulatory mechanisms all of which are not yet understood. Of the glands concerned in regulating the level of blood calcium, the parathyroids, small structures in the neck in the neighbourhood of the larynx, are the most important. If these are removed experimentally the blood calcium at once falls but can be restored by injecting parathyroid extract. So long as they are in good working order they, in co-operation with the nervous system, bones, intestines, and kidneys, keep the blood calcium between narrow limits (usually 8 to 11 mg. p.c.), so that even when the food contains too little the level is kept up by calling on skeletal reserves. This can go on even when the skeleton has been tapped to the point of disease.

Before proceeding to a consideration of skeletal diseases caused by mineral-deficiency a few paragraphs may be devoted to hypocalcaemic disorders.

Hypocalcaemia.—For a general understanding of the problem the reader may be referred to the recent lengthy review [4] of Schmidt and Greenberg on 'Occurrence, Transport, and Regulation of Calcium, Magnesium, and Phosphorus in the Animal Organism', and to Carlström's paper [5] on 'Hypocalcaemic Morbid Conditions in Domestic Animals'. The commonest example is the well-known 'milk fever', a disorder far commoner amongst civilized dairy cows bred for high milk-production and fed on mineral-rich rations than it is amongst low-yielding cows reared under ranching conditions even in areas poor in minerals. The typical disease occurs just after calving, comes on suddenly, and may terminate in coma (complete unconsciousness). It is therefore often termed 'puerperal paralysis', and under this name has been described in animals other than the cow, e.g. in the ewe, where it is also termed 'lambing sickness'.

The common fall in plasma calcium is from the normal value of about 10 mg. p.c. down to half or less (range 7 mg. p.c. to 2 mg. p.c.) and is quite sudden. Any factor which temporarily raises the calcium level promptly alleviates the symptoms, and the animal then usually makes an uneventful recovery. This may be accomplished by distension of the udder, as in the well-known curative treatment by inflation with air, or by injection of a soluble calcium salt into a vein or under the skin. The salt generally used is calcium gluconate or the more soluble borogluconate [6], because they are less irritant than the chloride. The small amount of calcium injected disappears from the blood in a few hours, so that it is not a question of supplying calcium needed by the body but merely of correcting the hypocalcaemia for the moment. Nature does the rest. In udder-inflation the older view was that damming back the

milk flow stopped the drain of calcium from the blood, but the observations of Montgomerie [7] on equine hypocalcaemia, in which symptoms were alleviated by injection of air into the subcutaneous tissues, suggest that nerve-stimulation plays a part.

All the evidence on causation points to a temporary disturbance of the 'nervous endocrine' controlling mechanism described above, and the fact that even in normal calving of dairy cows distinct changes in blood calcium, magnesium, and inorganic phosphate occur at the time of parturition [8, 9] suggests that the hypocalcaemia of puerperal paralysis is only a pathological exaggeration of normal physiological changes. Just after calving there is an enormous increase in calcium metabolism and this has to be met by increased absorption from the food. The increased demand is quite sudden, and to tide over the period until a new balance is struck between rate of absorption and rate of elimination the reserves of the skeleton are mobilized. When it is considered that the blood has to carry the calcium to the udder but that a single gallon of milk or half a gallon of colostrum contains more calcium than is present in the total blood-stream at any given moment, it will be obvious that lactation involves suddenly increased effort upon the part of the physiological controlling mechanism which keeps up the calcium level of the plasma. Normally the response is immediate and apart from a small temporary downward swing of blood calcium, followed by a compensatory swing in the opposite direction a few days later, the mechanism performs its task. The theory is that if it lags behind in its response, the blood calcium drops too far and symptoms of so-called milk fever appear (tetany leading to coma). If the hypocalcaemia is rectified by treatment the physiological mechanism apparently gets a chance of reasserting its control. The response to a single injection of a calcium salt is often spectacular; a comatose cow may rise and behave almost normally half an hour after artificial restoration of the balance of blood minerals by direct introduction of a quantity of calcium trifling in comparison with the enormous mobilizable reserves of the skeleton—which, it is assumed, could not be called up fast enough because of temporary failure of the controlling mechanism.

Skeletal disorders.—Not so long ago the skeleton was regarded mainly as a supporting framework which sheltered the active blood-forming red marrow and to which other tissues such as the muscles were attached. It is now known, however, that the hard bone is itself an actively metabolizing tissue, which undergoes continual changes right throughout life, and that the skeleton is the great nutritional reservoir for the important minerals calcium and phosphorus, and probably also for magnesium. The response of the skeleton to demands from the blood is rapid, and the extent to which it can suffer resorption before failing in its structural functions is very great.

Osteoporosis.—The organic matter of bone (ossein) is impregnated with complex earthy salts which confer strength and rigidity. The basis of these is calcium phosphate, but since the elements calcium and phosphorus are necessary for other physiological purposes, the skeleton is drawn upon whenever they are not being absorbed from the digesting

food in amount sufficient for the organism as a whole. It is not a matter of 'leaching out' of minerals but of actual break-down of bone, the portions least needed for structural purposes being resorbed first, e.g. the trabeculae and inner lamellae of the long bones. The skeleton thus becomes lighter and more porous, and to this condition, if at all pronounced, the term 'osteoporosis' is applied. When more minerals are absorbed from the food than are needed for general physiological requirements the balance is restored, fresh bone is laid down, and the skeleton reaches its maximum weight and compactness.

With a normal domesticated animal, not specially bred for high production and on a ration containing sufficient calcium and phosphorus, the nutritional function of bone as a mineral reservoir is little utilized, but in a state of nature where the natural food may suffer seasonal variations in mineral-content it may come into prominence—as on the phosphorus-deficient pastures of South Africa, Australia, and elsewhere [10]. In the modern high-yielding dairy cow it may also play an important if not obvious role, even when the ration contains abundance of minerals. In many cases breeding for high production has evolved an animal which may have an udder capable of producing milk, rich in calcium and phosphorus, faster than its intestinal walls can absorb these elements into the blood-stream from the digesting food in the lumen of the gut, so that it 'draws upon its convenient skeletal bank however high its dietary income may be' [10]. Meigs and his co-workers state that the total calcium loss of a cow usually does not exceed 20 per cent. of its total skeletal supply, and as a rule there is no serious interference with the milk yield until the losses exceed this figure; but such an animal is nevertheless almost pathological, oscillating between compact bone at the end of the dry period and a mildly porotic framework at the height of lactation. The process of bone-resorption, however, rarely proceeds to the danger-point, so that Theiler, in his consideration of the 'Osteodystrophic Diseases of the Domesticated Animals' [1], does not regard osteoporosis as a disease in itself so much as a 'stage in the evolution of some disease the last phases of which may not always be reached'. In extreme cases, however, so much bone may be removed that the skeleton becomes fragile, e.g. in the records of Becker, Neal, and Shealy [3] a cow averaged 6,338 lb. of milk in eleven consecutive lactations and then broke her pelvis in three places.

Osteomalacia and rickets.—If for any cause a skeleton becomes weakened by bone-resorption it usually attempts to repair the damage by laying down osteoid tissue (organic matrix) in preparation for subsequent calcification (deposition of minerals), but if it is unable to complete the process the bone is softer and more easily bent. To this condition of excessive uncalcified osteoid tissue the technical term 'osteomalacia' is applied. If the bone is still growing, the epiphyses, or terminal portions separated from the long bones by cartilage in early life (but later becoming part of the larger bones), are affected and the stresses on the proliferating cartilage give rise to the well-known distortions characteristic of rickets. But there is no fundamental difference; whether the failure to calcify osteoid tissue is manifested as rickets

or as osteomalacia simply depends upon the age of the animal at the time the causal factors operate. The pathologist groups both diseases under the term 'osteodystrophia malacia', and in animals which are born with a well-developed skeleton the bone picture may be a mixed one, e.g. in the calf which may show mixed rickets and osteomalacia, as compared with the human infant which shows the more typical histological picture of rickets. A detailed description of the pathology of these diseases will be found in the article by Theiler already referred to [1].

The causal factors may be deficiency of calcium, or of phosphorus, or of vitamin D, or of any combination of these. All three are necessary for normal bone metabolism, although some writers [11] maintain that calcium is necessary for formation of osteoid tissue, and hence that osteomalacia is characteristic of aphosphorosis and avitaminosis, whilst straight acalcicosis is manifested typically as simple resorption or osteoporosis.

If either calcium or phosphorus is missing it is obvious that calcium phosphate cannot be deposited. The part played by vitamin D is not quite clear, but in some way it controls absorption of calcium by the intestine and consequent mineralization of osteoid tissue. It either has to be present in the food as such or in the form of precursors which the body can use to manufacture ergosterol, a substance which can be converted into vitamin D by the action of sunlight on the skin. Hence if vitamin D is not present as such in sufficient amount in the food, the absence of sufficient sunlight may become the determining factor in the causation of rickets. In children the cause of rickets is vitamin-deficiency, often associated with insufficient dietary calcium. The value of cod-liver oil in preventing and curing rickets is due to the fact that this oil is rich in vitamin D and that with abundance of this vitamin whatever calcium is in the food is better utilized.

With grazing animals, however, the sunlight to which they are exposed is sufficient to activate the vitamin precursors they synthesize from the food, and osteomalacia and rickets do not occur naturally as a D-avitaminosis. They do, however, occur on a wide scale in different parts of the world as an aphosphorosis, wherever the natural pasture is deficient in phosphorus. The article by Theiler and Green [10] on 'Aphosphorosis in Ruminants' reviews the world position in this respect, and also deals with indirect economic consequences of phosphorus-deficiency. The 'styfsiekte' of South Africa, the 'cripples' of Australia, and the 'knochenweiche' of central Europe are all cattle diseases which should be called 'bovine osteomalacia' and are due to phosphorus-deficiency. Aphosphorosis is also common in sheep and passes under various local names such as 'osseous cachexia'. As indirect consequences of phosphorus-deficiency, not so acute as to lead to pronounced osteomalacia itself, may be mentioned retardation of growth, protective cessation of ovulation leading to reduced fertility, production of pathologically fine wool-fibre in the case of sheep (incidentally higher priced per lb. on the wool market), and osteophagia (bone-chewing) or depraved appetite leading to ingestion of material which the normal herbivore

would shun. If carcase material, common under ranching conditions (animals dying from other causes and not buried, wild game, rabbits exterminated by poison), happens to become infected with the toxicogenic saprophyte *Clostridrium botulinum* in the course of putrefaction, it may become so toxic that a few ounces of skeletal debris is fatal to an adult bovine; acute fatal botulism ('lamsiekte' in South Africa, 'bulbar paralysis' in Australia) then appears as a sequel to osteophagia, and may be obviated either by eliminating the carcase debris itself, or by correcting the depraved appetite by phosphatic supplements. Such additional nutritional phosphorus at the same time corrects the hypophosphataemia (low blood phosphorus), permits normal growth and reproduction, and, of course, eliminates the osteomalacia characteristic of extreme aphosphorosis.

Theoretically, skeletal disease could also occur as an 'acalcicosis', but since in the leafy parts of plants calcium usually preponderates over phosphorus, and minimum physiological requirements for the latter elements are higher, it does not appear in grazing animals from that cause.

In Great Britain even the poor pastures are generally sufficiently rich in phosphorus and calcium, although low by comparison with the best pastures, so that osteomalacic diseases do not occur in grazing animals, except perhaps under the exceptional conditions attending the Scottish 'croitich' [12]. This does not mean that the animals would not, in some cases, benefit by mineral supplements—only that the deficiency is rarely so pronounced as to lead to the clinically recognizable disease osteomalacia.

In Britain the farm animal most likely to develop rickets or osteomalacia is the pig sty-fed on rations from which the conventional supplement of ground limestone has been omitted. It may then arise as a combined deficiency of calcium and of vitamin D or its equivalent sunlight. This is because the pig is fed so largely on products derived from cereals which, although rich in phosphorus, are notoriously poor in calcium and contain little preformed vitamin D. Good hygienic conditions and the inclusion of minerals, usually 1 per cent. of chalk or ground limestone, 1 per cent. of bone-flour, and $\frac{1}{2}$ per cent. of salt in the mixed meal, are sufficient to prevent skeletal disease in the pig. A small amount of cod-liver oil is also useful, not only as supplying additional vitamin D but as protecting against the possibility of deficiency of vitamin A [13].

Since calcium-low grain food also predominates in the rations of poultry the same precautions apply. Birds without access to calcareous grit may develop skeletal disease as an acalcicosis, or if insufficiently exposed to sunlight develop it as an avitaminosis.

Osteofibrosis.—This disease is chiefly known in equines and goats, but also occurs in the pig and the dog, and is then usually complicated with rickets and osteomalacia [1]. It has not been described in cattle or sheep and has been chiefly investigated in the horse. It sometimes goes under names such as 'equine osteomalacia' and 'osteoporosis', but these are misnomers since microscopic examination of the bones shows

it to be a distinct disease. As the name 'osteodystrophia fibrosa' or 'osteofibrosis' implies, the characteristic feature is the predominance of fibro-cellular material in the bones and not of osteoid tissue, as in osteomalacia.

The disease occurs sporadically all over the world and may appear as regional outbreaks, especially in the more tropical countries. The occasional form is often referred to as 'bran disease' or 'miller's disease' in Europe, and in England as 'big head'.

The disease develops slowly, usually runs a course of several months but may last for years in less acute form. In the early stages it often passes unrecognized, but as time goes on lameness becomes pronounced, the horse loses condition, and various skeletal deformations appear, the most characteristic feature being a thickening and softening of the jaws. The whole skeleton is weakened and may be reduced even to half its normal weight before death supervenes, but the damage may proceed to danger-point before external signs are obvious—as in recorded cases of racehorses suffering fractures during an actual race.

Over the years 1923–31, before the cause was clearly understood, it was the most serious disorder amongst the military horses in the Philippines [14]. In Britain the extreme forms are rare, but the extent to which a subdued chronic form is a contributory cause of disabling disorders of horses (lameness, exostoses, i.e. growths on bone surfaces, arthritis) requires further investigation. Whatever be the intermediary physiological mechanisms leading to osteofibrosis, the primary cause is now known to be nutritional—a large relative excess of phosphorus over calcium in the dietary. It may occur on rations in which the calcium is too low without the phosphorus being unduly high, as in the barley-feeding experiments of Niimi and Aoki in Japan [15], or it may occur in presence of adequate calcium with a large excess of phosphorus, as in the original bran-feeding experiments of Crawford in Ceylon. The later work of Kintner and Holt [14] has put the critical dietary ratio of lime to phosphoric oxide ($CaO : P_2O_5$) as between 1 : 2 and 1 : 3, but even on a ratio of 1 : 5 the disease may take over a year to become obvious.

It is now easy to understand the conditions under which the disease appears. Since in pasture grass the proportion of calcium usually exceeds that of phosphorus the disease will rarely appear in grazing horses. Since cereals and bran contain large excess of phosphorus over calcium it is likely to appear in stabled horses whenever the supply of concentrates is high in relation to roughage, and particularly when a heavy bran-ration happens to be associated with hay unusually poor in calcium. It is likely to break out as a local disease amongst military horses or in large stables in which the ration is prescribed by authority.

Bran has a wide ratio $CaO : P_2O_5$ of about 1 : 14, barley about 1 : 12, maize about 1 : 30 or wider, oats about 1 : 6; clover hay shows the narrow ratio of about 0·3 : 1, English meadow hay about 0·5 : 1, calcium-poor hay 1 : 1 or wider. If we take the ratio 1 : 2 for the complete ration as sufficiently narrow to prevent the disease, it is easy to understand why it is more likely to occur in maize-growing countries than in oat-growing countries, to be associated with areas which yield

calcium-low forage, and in Europe to acquire a name like 'miller's disease' (horses fed on excessive quantities of milling by-products).

In any case prevention, and cure in the earlier stages, is simple. It is already general practice to give a mineral supplement to pigs and poultry. A similar supplement would serve for horses; or ground limestone alone in amount calculated as sufficient to keep the whole ration to a ratio not wider than 1 : 2. In thinking in terms of ratios it should, of course, be made clear that the significance is elastic. The virtual ratio is not necessarily the real ratio of available calcium and phosphorus since certain compounds, such as the phytin of cereals (the calcium salt of inositol hexaphosphate), are very difficult to assimilate.

Magnesium

In considering magnesium the distinction already made for calcium, between food magnesium and blood magnesium, is even more striking. Several disorders are characterized by hypomagnesaemia but not by magnesium-deficiency, the best known being 'lactation tetany' or 'grass tetany' of cows.

The dietary magnesium requirements of an animal are very low and are covered by all ordinary rations, so that although magnesium-deficiency disease has been produced experimentally in rats and puppies [16] by using specially purified synthetic diets, it is very doubtful whether it will ever be found to occur naturally in farm animals. The tetany of milk-reared calves is attributed by Duncan, Huffman, and Robinson [17] to magnesium-deficiency or failure to utilize dietary magnesium, and by Sjollema [18] to protein-intoxication, but the observed hypomagnesaemia might be caused by any factor which upset the physiological mechanism controlling the level of blood magnesium.

The nature of this mechanism is unknown but, as in the case of calcium, it is presumably 'nervous endocrine'. There is, however, no reason to incriminate the parathyroids, since the hypocalcaemia which follows experimental extirpation of these glands is not accompanied by hypomagnesaemia [19]. Cannavò [20] has suggested the anterior lobe of the pituitary gland as controlling plasma magnesium, but the evidence is unsatisfactory.

When hypomagnesaemia appears suddenly it may occur alone, as in typical acute grass tetany of cows, or associated with hypocalcaemia as in 'transit tetany' of horses, or as in a mixed disorder of cows which may terminate either in coma or in convulsive seizures. A chronic hypomagnesaemia, not associated with tetany but rather with cachexia (general malnutrition), has been described by Blakemore and Stewart [21].

Lactation tetany or grass tetany.—This disease has come into prominence in England over the last decade, but most older veterinary practitioners have seen it in their youth without giving it a specific name. In Holland it is called 'grass tetany' because it occurs most typically just after the cows are turned out from stall to pasture. Sjollema [22] states that the incidence has much increased with increasing intensity of grassland management in Holland, but it seems probable that the breeding of cows for high production is the main cause of its

increased incidence throughout the world. In New Zealand it occurs in cows pastured all the year round, most commonly in spring.

In England the incidence is also seasonal and more cases occur in April, May, and June than in all the other months put together. It has, however, been occasionally reported in stalled animals in mid-winter, in almost dry cows, and at least once in a male.

The onset may be sudden, symptoms alarming, and fatal termination rapid. In its most acute forms death in convulsions may follow an hour after the first symptoms are noticed, but more usually the veterinary surgeon can reach the cow in time for successful treatment.

Hypomagnesaemia is the characteristic feature of lactation tetany and in extreme cases the plasma magnesium may vanish almost entirely. From a normal value of about 2·3 mg. p.c. the level may drop to 0·2 mg. p.c., although a common figure is 0·7 mg. p.c.; say one-third normal. Blood calcium may remain normal but usually falls appreciably.

Nervous 'irritability' is related to the level of plasma magnesium. If this falls much below normal the response to stimuli is too active and muscular tremors, spasms, and finally convulsions appear. If it is artificially raised by injection of magnesium salts nervous irritability is reduced until finally, at the very high level of about 17 mg. p.c., complete anaesthesia occurs. Treatment of lactation tetany consists in temporarily raising the level of blood magnesium by intravenous or subcutaneous injections of magnesium, so alleviating the symptoms and allowing natural recovery to take place. For this purpose magnesium sulphate is cheapest and as good as any other salt. It is non-irritant and can be injected in highly concentrated solution, usually 50 c.c. to 100 c.c. of a 20 per cent. solution for intravenous injection, or up to about 300 c.c. of a 30 per cent. solution for subcutaneous injection. Absorption from a subcutaneous injection is slower but is continuous and maintains the artificially raised blood level for a longer period of time.

With regard to the underlying cause of lactation tetany there is little precise information. Like milk fever it is almost certainly due to dysfunction of a 'nervous endocrine' regulating mechanism, but no particular gland has been successfully incriminated. The suddenness of fall of plasma magnesium and the rapid response of acute cases to magnesium therapy suggest a physiological controlling mechanism which in susceptible animals is disorganized by a variety of 'precipitating causes'. Sudden change of environment, a railway journey, change from winter rations to rapidly growing young grass, presumably certain toxic factors, may all precipitate an attack. Probably slight attacks are more frequent than generally supposed—slight tremors followed by spontaneous adjustment of the regulating mechanism.

The chronic hypomagnesaemia recorded by Blakemore and Stewart [21] is still more obscure and does not respond to magnesium injections.

Mixed condition.—Until recently milk fever and lactation tetany have been considered independently, but Allcroft and Green [23] have plotted charts to show that a mixed condition in which both hypocalcaemia and hypomagnesaemia are pronounced is nearly as common in some districts as either alone. A plain hypocalcaemia or hypomagnesaemia can pass

over into the mixed disorder within 24 hours, and this suggests that the controlling mechanisms for plasma calcium and magnesium are interrelated.

The mixed condition may occur at any time, either as a complication to milk fever at the time of parturition, or as a complication to lactation tetany during the season of greatest incidence of that disease, or at any other time as an atypical manifestation of either disorder.

In such cases many veterinary practitioners combine calcium and magnesium therapy, or fall back on udder inflation. Fortunately the temporary rectification of either the hypocalcaemia or the hypomagnesaemia is frequently followed by spontaneous readjustment of both.

Transit tetany.—This term has been applied to a similar disease of lactating mares but which may also occur in stallions. Hypocalcaemia was demonstrated by Montgomerie, Savage, and Dodds in 1929 [7], and further associated with hypomagnesaemia by Green, Allcroft, and Montgomerie in 1934 [24]. The disorder is thus parallel to the mixed condition just described for cows although the 'precipitating cause' is different. In the equine cases the disturbance appeared in mountain ponies reared on grass, after a sixteen-hour railway journey to the Menai Bridge Fair. One of the original cases of Harvey [25] occurred after transfer from pasture to stable. Among cows the commonest precipitating cause is the reverse transfer from stall to pasture, but there are records of recovered cases of lactation tetany relapsing after transit to market.

The condition has also been described in sheep although as yet few blood studies have been made in respect of magnesium.

Iron and Copper

Iron and copper may be considered together because of their association in 'nutritional anaemia' of the domesticated animals. Anaemia, i.e. lowered haemoglobin of the blood, or reduced numbers of red corpuscles, often associated with change of size and altered haemoglobin-content of each corpuscle, may arise from various causes (e.g. worm infestation) but may be of nutritional origin. In the 'bush sickness' of cattle and sheep in the Rotorua district of New Zealand originally investigated by Aston, the 'salt sick' of Florida [26], the 'nakuruitis' of Kenya [12], and the 'pining' of Scotland [27], iron licks alone, but preferably with a trace of copper, prevent the condition, although it is by no means certain that iron-deficiency alone is the sole cause. In the case of the 'lecksucht' of cattle, sheep, and goats more recently described by Sjollema [28] in eastern Holland, an actual deficiency of copper in the vegetation seems to be incriminated and copper therapy alone is more effective than iron therapy alone.

Since the idea that copper is an essential element in nutrition is comparatively new the present views on its functions and its relation to iron may be briefly explained. Iron is an essential constituent of haemoglobin, the red oxygen-carrying matter of blood which is packed into the erythrocytes or circulating red blood corpuscles. These are formed from various precursor cells in the 'haematopoietic tissue' which fills

the cancellous spaces of the bones, and are then discharged into the blood-stream. If an experimental animal is fed upon a diet deficient in iron and copper, the erythrocytes are not formed in sufficient numbers and not always properly packed with haemoglobin, so that a 'nutritional anaemia' results. If a purified iron salt is now added to the diet, iron is stored in the liver but very little formation of haemoglobin occurs in the red marrow unless traces of copper are also added. If copper is then substituted for the iron the liver reserves are mobilized and haemoglobin is formed. Addition of copper alone to the deficient diet brings about an increase in the number of reticulocytes (reticulated erythrocytes) in the blood but the total haemoglobin formation is small.

Addition of iron following the copper now produces a second 'reticulocyte response', but this time with normal haemoglobin formation. It would thus appear that copper assists in the mobilization of iron in the body and in the formation of haemoglobin. The reason why the significance of copper has been overlooked in the past is that the quantities required are so small that the traces present in most foods are sufficient. It is therefore of special interest that Sjollema should attribute a naturally occurring disease of domesticated animals to copper-deficiency in certain pastures.

Pig anaemia.—The case of pig anaemia is different from the anaemia of 'bush sickness' and 'pining', since it is not the food of the adult which is incriminated but the composition of the sow's milk in relation to the requirements of the litter. From time immemorial mother's milk has been regarded as the perfect food for the infants of all species, but apparently the intervention of man in selectively breeding pigs for phenomenal production has created a situation in which the demands of the fast-growing pigling for rapid haemoglobin formation have outrun the capacity of the mother to supply sufficient iron through the milk. The fact that some piglings in a litter suffer more than others, and that some litters suffer more than others under apparently the same conditions, suggests a genetic factor—perhaps operating as a capacity to make the best use of the small amount of iron available.

The anaemic condition is characteristic of sty piglings and rarely occurs in pigs farrowed out of doors and reared on grass runs, where a little extra iron is incidentally obtained by early rooting and swallowing of soil particles. It is easily prevented under sty conditions by supplying a little iron direct to the piglings—not to the mother, who is already well supplied from her own food but is unable to increase the amount in her milk.

Prevention can sometimes be accomplished by throwing freshly cut grass sods, preferably impregnated with iron, into the sty, but is more certainly accomplished with very little trouble by painting the udders of the sows with a suitable iron mixture at least once a day. A common mixture is $3\frac{1}{4}$ oz. of iron sulphate and $\frac{3}{4}$ oz. of copper sulphate dissolved in a pint of water and then mixed with a pint of treacle or syrup to make the solution sticky and more palatable.

Pig anaemia is much commoner than many breeders suppose. For

instance, Doyle, Mathews, and Whiting [29] give certain records from the United States in which 89 per cent. of the deaths up to 8 weeks after farrowing were attributed to anaemia. Aderson [30] and Olofsson [31] stress the economic importance of pig anaemia in northern Europe. Foot [32] refers to the death of 10 per cent. of the pigs born at the National Institute for Dairy Research at Reading over the years 1931–3 from anaemia during the first 8 weeks of life, and to successful subsequent prevention by administration of iron.

In general the piglings are born with normal haemoglobin, which ordinarily falls somewhat over the first 10 days and then rises again if the iron supply is adequate, but which continues to fall if it is not, so leading to a pathological anaemia. The pigling may succumb, or recover as soon as it begins to take sufficient food independently of the mother's milk. When death supervenes it is not always as a simple result of the anaemia, and when recovery occurs it is not always perfect. The piglings suffer a set-back and in their weakened state are more liable to contract secondary disorders to which the healthy pigling is more resistant.

Iodine

Iodine-deficiency in acute form is comparatively rare in farm animals except in certain well-defined areas of the world, but may occur sporadically even in Britain. Rationed animals may sometimes receive sub-optimal quantities of iodine and benefit by iodized salt. On the other hand, indiscriminate use of iodine supplements in excessive amounts may have adverse effects [33].

One of the best-known cases of acute deficiency occurring on a large scale was recorded from certain American states in which 'foetal athyrosis' [34] or 'hairless pig malady' occasioned considerable losses prior to 1917. Piglings were still-born, or born hairless and died shortly after birth, even when the mothers were apparently healthy. The trouble was dissipated by including traces of potassium iodide in the rations of the breeding sows. Sporadic cases of foetal athyrosis have been observed in England on very badly constructed rations.

Goitre in sheep was at one time prevalent in Michigan and prevented by adoption of salt containing traces of iodine. Goitre in sheep, cattle, and goats has been reported from Canada, Switzerland, New Zealand, and elsewhere, and correlated with iodine-deficiency in drinking water and pasture. An 'Iodine Survey of New Zealand Livestock' has been made by Mason [35], who places the critical value for iodine in sheep's thyroid at 0·03 per cent. on the fresh gland; below this the gland increases in size as the iodine-content diminishes, sometimes reaching a weight of fifty times the normal. Salt licks containing 3 oz. of potassium iodide per cwt. of salt have successfully prevented further trouble. Hopkirk, Dayus, *et al.* [36] reported an outbreak of congenital goitre in lambs, all of which were born weak with enlarged thyroids, whilst many were hairless or deformed. Sporadic cases of a similar nature, involving a small proportion of lambs in a flock, have been reported from Somerset and Dorset in areas known to be border-line in respect of iodine, and although the problem of iodine-deficiency is not acute in

British farm practice the question of 'iodine intake below the optimum' merits further investigation.

Iodine-deficiency is usually reflected as 'thyroid hyperplasia': as soon as the store of iodine in the gland falls below a certain level the thyroid tissue increases in an endeavour to produce a sufficiency of its iodine-containing hormone to meet physiological requirements. But direct iodine-deficiency is not the only cause of thyroid hyperplasia, and any factor which reduces absorption of iodine or increases the utilization of the thyroid hormone may also cause goitre. In the human subject sporadic goitre can occur in localities rich in iodine. Spence [37] gives an account of the production of goitre in rabbits by cabbage-feeding, and shows that it is dependent upon a positive goitrogenic substance destroyed by air-drying and not dependent only on the iodine-content of the cabbage. He also discusses the presence in certain plants of anti-goitrogenic substances other than iodine. Continuous administration of certain organic cyanides may be goitrogenic by depressing tissue-oxidation and so producing a compensatory reaction on the part of the thyroid gland, the iodine-containing hormone of which raises the metabolic rate.

In theory, simple goitre is due to iodine-deficiency; in practice it is due to a combination of factors which bring out the insufficiency.

Fluorine

The element fluorine is mentioned not because any case of fluorine-deficiency has ever been suspected, but because 'fluorosis' due to excessive fluoride-content of certain drinking waters, or use of mineral supplements rich in fluorine for correcting phosphorus-deficiency, has been recorded. The disease 'darmous' affecting all domesticated animals, but particularly sheep, in the rock-phosphate areas of North Africa is discussed by Velu [38, 39] as a spontaneous fluorosis.

Hupka and Gotze [40] reported cases of fluoride poisoning in cattle. Du Toit, Malan, Groenewald, and de Kock [41] record an experimental study of the effects of fluoride on pregnant heifers. Loss of weight and swellings on the long bones of the extremities were the characteristic features. One heifer died before calving and the other had to be destroyed. In the more chronic fluorosis of 'darmous' in Morocco the most characteristic feature is dystrophy of all the permanent teeth, which takes the form of erosions in the enamel; the teeth wear down quickly and the animal is unable to feed.

Sodium, Potassium, and Chlorine

It is not proposed to discuss the physiological functions of these elements, and since no naturally occurring diseases have yet been proved to be due to deficiency or imbalance between them little need be said. 'Salt hunger', manifested as a craving for salt, is well known in areas in which the vegetation is low in sodium or chlorine, and a salt lick is commonly supplied to farm animals, even if only as a condiment. Much has been written on the importance of the ratio of sodium to

potassium in a ration and some of the earlier views on alkali-deficiency in relation to the lecksucht of East Prussia have been discussed by Green [42], but earlier theories have not stood the test of time. Orr includes a discussion of these elements in his 'Minerals in Pastures' [12].

In natural pastures potassium greatly exceeds sodium and no deficiency of potassium has ever been suspected. Sodium and chlorine may sometimes be very low but the extraordinary tenacity with which sodium chloride is retained in the body in times of shortage is an automatic safeguard against deficiency. Although the kidneys can readily excrete large excess, the urine becomes almost chloride-free when the diet is rendered salt-free, so that it is not an easy matter to produce a 'sodium chloride deficiency disease' by dietary régime alone. If, however, a secretion such as the gastric juice is simultaneously drained off by operative procedure the animal is unable to protect itself against loss, and symptoms of chloride-deficiency rapidly appear. The external secretion milk is rich in chloride, so that salt may become a limiting factor in milk production—the defence of the animal being protective cessation of lactation. Of recent experiments the data of du Toit, Malan, and Groenewald [43] are of considerable interest. They fed heifers on a basal ration low in minerals containing 6·7 gm. chlorine (Cl), 5·7 gm. soda (Na_2O), and 29·3 gm. potash (K_2O) for the whole period of gestation and early months of lactation. No adverse effects were noted until lactation began and drained off about two-thirds of the sodium and chlorine. Milk yield rapidly fell off, from 24 lb. to 2 lb. within 3 months. These figures give some indication of minimum requirements for maintenance and suggest that the sodium- and chlorine-contents of pastures would have to be astonishingly small before adverse effects, other than protective cessation of lactation, would appear. The authors suggest that about 14 gm. Cl, 15 gm. Na_2O, and 38 gm. K_2O are sufficient in the daily ration of a cow producing 2 gallons of milk. On this basis the sodium-content of certain sodium-low pastures in various parts of the world would be insufficient for adequate milk production without a salt lick, but not necessarily inadequate for survival of the animal itself.

Summary

A brief survey of the dietary significance of phosphorus, calcium, magnesium, iron, copper, iodine, fluorine, chlorine, sodium, and potassium is given with reference to diseased conditions in the animal, such as osteoporosis, osteomalacia, rickets, osteofibrosis, nutritional anaemias, and hypomineralaemias.

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THE NYASALAND TOBACCO INDUSTRY

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NYASALAND is a strip of country 500 miles long in tropical Africa. It stretches from latitude 9° S. to 17° S. and for most of its length it lies between Lake Nyasa and Northern Rhodesia. The southern portion is enveloped by Portuguese East Africa and in the extreme north it adjoins Tanganyika. It has no seaboard and communicates with the outside world through the Portuguese port of Beira with which it is connected by rail. A railway bridge across the Zambezi River was completed this year, and it is now possible to carry produce from the shores of Lake Nyasa to Beira without transhipment.

Blantyre and Limbe are the largest towns. Limbe is the tobacco-marketing centre and here the factory of the Imperial Tobacco Company is situated. It is 345 miles by rail from Beira, and 275 miles by road from Quilimane.

The native population exceeds one and a half million and consists of a number of tribes of which the most numerous are the Angoni and Achipeta in the north, and the Yao and Nyanja in the south. Much of the labour on the tobacco and tea estates is supplied by the Anguru, a race that lives mainly in the adjoining Portuguese territory.

On the whole the soils are very fertile. Most of the country is between 2,500 and 4,000 ft. above sea-level. The rainy season lasts from November to April, and the rainfall ranges between 25 and 45 in., except in the tea districts, where it reaches 55 to 70 in. A little effort during the rainy season provides the native with sufficient foodstuffs—maize, beans, cassava, millet—for his needs throughout the year. A hut tax of 6*s*. per annum is levied and this makes it necessary for him to work on the European tobacco or tea estates or to grow produce for sale. The principal native crops grown for this purpose are tobacco, cotton, and maize.

Introduction of the tobacco plant.—It is generally agreed that the tobacco plant is not indigenous to Africa, but came from America by way of Europe through the agency of early Portuguese explorers or traders. It was unknown to Europeans before the first voyage of Christopher Columbus to America in 1492. Seeds were carried to Spain and Portugal between 1556 and 1560, and tobacco was grown in the Royal Gardens at Lisbon in 1558. The Portuguese explorer, Vasco da Gama, rounded the Cape of Good Hope in 1495, and traders followed who established settlements along the east coast and up the Zambezi River. There seems little doubt that the tobacco plant was introduced through these early settlements and that it was soon carried into the interior by the natives.

In De Flacourt's *Histoire de Madagascar* (1661) reference is made to the cultivation of tobacco by the natives of that island. When Dr. Livingstone explored the Zambezi Valley and the country round Lake Nyasa (1851–73) he found that tobacco was grown everywhere. His companions on one expedition, Sir John Kirk and Mr. J. C. Meller, sent

specimens of the plant to Kew, where it was classified as *Nicotiana tabacum*, the species native to America.

In his book *British Central Africa* (1889), Sir H. H. Johnston, who was H.M. Commissioner and Consul-General to the territory now called Nyasaland, wrote as follows:

> Of his cultivated plants, maize, manioc, sweet potato, tobacco, tomato . . . reached him from America. Although these things are now spread right across Africa in their cultivation, they are natives of America and were introduced from two to three centuries ago by the Portuguese.

The Nyasaland tribes have no common name for *Nicotiana tabacum*, the pink-flowered species of tobacco. It is known as 'fodia' by the Nyanja, Chipeta, Chisena; 'hoona' by the Chihenga; 'sona' by the Yao. This diversity of names may indicate the antiquity of the original importation. The original strain may still be grown for local use in remote districts. In the developed districts any pink-flowered variety is referred to as 'fodia'.

There is also a yellow-flowered species grown by the natives for snuff-making called 'labu' (Nyanja and Yao). Seed which was sent home by the writer was identified at the Royal Gardens, Kew, as *Nicotiana rustica* var. *asiatica* Schrank. This species is cultivated also in North Africa and Syria, and was probably introduced into Central Africa by Arab traders.

The natives of this part of Africa have grown tobacco for about 300 years.

Development of the industry.—Nyasaland was declared a British Protectorate in 1889 and tobacco first figured among the exports in 1893. Production steadily increased and the progress of the industry may be judged from the following table of exports of tobacco of all types:

	lb.		*lb.*
1911	2,146,615	1926	9,142,437
1913	3,763,014	1928	11,632,497
1916	4,304,124	1930	12,934,914
1918	5,805,396	1931	10,690,581
1920	4,963,130	1932	15,082,035
1922	6,330,808	1933	10,394,498
1924	7,044,175	1934	12,544,126

This development was due to the European settlers who had taken up land in the district roughly 40 miles north and south of Blantyre. The labour force required was considerable, and whilst a nucleus was employed throughout the year, the majority was made up of labourers engaged for the season of five or six months. The operations of sowing, transplanting, cultivation, topping, and curing were controlled by the planter through 'capitaos' (overseers) selected from the labour force for their intelligence and reliability. Many of these men became able growers, and learnt the art of fire-curing from the settlers. They had long been accustomed to curing their own tobacco and drying it on the roofs of their huts, but the method of using sheds and smoke from smouldering logs was new to them.

Since 1920 great changes have come about owing to various factors, such as the changes in market requirements, the fall in commodity prices, opening of new areas to production and native developments. The cigarette has become increasingly popular, and for this purpose a bright type of cured leaf is required which is the natural product of light sandy soils. Climatic conditions greatly influence the yields per acre and thus affect the cost of production. Soil and climatic factors are becoming more appreciated as they decide what type of leaf can be produced economically in a given area and the tendency is for the centres of production to move to the appropriate areas. The fall in prices has hastened this movement. More attention is being paid to quality so as better to supply the requirements of the market and to meet the competition of other producing countries.

The most pronounced increase has been in the native production of dark fired tobacco, which is used for pipe mixtures. Air-curing and fire-curing are simple operations compared with the flue-curing of bright cigarette leaf and most of the dark fired tobacco is now a native product. All the flue-cured tobacco is produced by Europeans.

Dark fired tobacco.—Strains of tobacco have been developed by breeding and selection to meet particular requirements, and the so-called Western types have been so obtained for air- and fire-curing. A strain which is popularly called 'Western' has been standardized by years of local selection, and Nyasaland fire-cured tobacco is almost exclusively of this strain. It probably has no exact counterpart to-day in the United States, its country of origin, and is now worthy of its official designation 'Western Dark Nyasa'. It shows good resistance to diseases, and stands up particularly well to local conditions.

Dark fired tobacco is produced in most parts of the country. A few pioneers opened estates in districts 200 miles north of the older settlements and produced leaf of excellent quality. The natives around took up tobacco culture extensively and at the present time most of the dark fired tobacco is produced in the Northern Province. The Government has done much to improve the quality of the product by the establishment of a Native Tobacco Board and Experimental Stations. The Board issues permits to native growers for the use of crown land, and supplies the seed at a small charge. It maintains tobacco instructors in recognized districts for the guidance and control of the native farmers in the matters of cultivation, topping, priming, curing, and grading. Buying stations or markets have been established at suitable centres and only such grades as are approved by official inspectors are allowed to enter the markets, thereby maintaining a high quality.

Tobacco appeals to the natives as a useful cash crop. Its expansion is limited by the requirements of a market which other parts of the Empire are also desirous of supplying.

Dark fired tobacco is produced on private estates also, by native tenants, and this meets with keen competition from that grown on crown land. The development of this class of tobacco can be judged from the following table, which shows the quantities of dark fired tobacco sold and the numbers of natives engaged in its production:

The crown-land grower has had considerable advantages in the past. His interest in a piece of land ceased after the crop was harvested. If fertility appeared to be falling off, he moved to a new spot and, following old native practice, burned off the timber as the easiest means of clearing it. This gave him a large application of lime and potash gratis and freed the soil from pests for a season. The maintenance of fertility did not worry him. On an estate, only too frequently is a bad patch explained by the remark 'an old native garden'. He uses no artificial fertilizer, but even sells his goat and cow manure to the nearest European planter.

Year	*Quantity sold*	*Number of growers*
	lb.	
1924 . . .	1,176,000	..
1925 . . .	2,636,480	..
1926 . . .	4,531,396	..
1927 . . .	7,804,757	66,321
1928 . . .	5,407,944	34,761
1929 . . .	8,694,253	47,578
1930 . . .	9,481,732	48,419
1931 . . .	7,883,139	51,903
1932 . . .	13,225,490	53,044
1933 . . .	9,131,911	56,026
1934 . . .	11,320,717	60,247

The European has invested his capital in an estate whose fertility he endeavours to maintain. He drains and terraces his fields to check erosion, rotates with legumes and maize, uses artificial fertilizer to improve the yield and quality, takes measures to control diseases and pests, and practises afforestation. There is no local market for his alternative crops, nor can they be exported profitably at the present time.

The differences of outlook and of land tenure between the white settler and the native have weighed greatly in favour of the latter, and if he were left to pursue the old native practices unchecked, the good tobacco-lands would quickly deteriorate and a valuable asset would be lost after a brief period of prosperity. The Native Tobacco Board has already done good work in connexion with growing and marketing the crop, but the fundamental principles of agriculture urgently call for attention so as to maintain the great asset of the country.

Flue-cured tobacco.—This class of leaf is produced exclusively by Europeans. The exports in recent years have been:

	lb.
1930	2,866,569
1931	2,590,253
1932	2,260,500
1933	1,644,479
1934	1,933,259

There has been a marked reduction of acreage and fall in production in the last few years. The types of leaf most in demand are semi-brights and semi-darks of good body, suitable for use in pipe tobaccos. The varieties Gold Leaf, Warne, Cash, Yellow Prior yield a good proportion of such grades when grown under favourable conditions.

The growth and curing qualities of the tobacco plant are very sensitive to weather conditions. Thus the saleable leaf from a given field may vary between 200 and 600 lb. per acre according to the season. Low temperatures, excessive rainfall, lack of sunshine, prolonged misty weather, wind, hail are all inimical. Temperature and rainfall control the rate and amount of growth. Misty weather favours the development of leaf diseases, which are sometimes responsible for great losses, particularly of the flue-curing varieties.

Some of the older estates were situated near the escarpments and in the mist zone. In such situations the odds are against the tobacco-planter, and this is where the main reductions of acreage have taken place. Outside this zone the grower has a better chance of planting with success. Land of low fertility is essential for the production of good-quality flue-cured tobacco; this has not been sufficiently appreciated in the past.

Successful tobacco culture demands a combination of appropriate climatic and soil conditions. A large surplus of land is necessary to enable fields to be rested to regenerate the conditions which are found in newly-opened land. Lastly, alternative crops are very desirable both for rotation purposes and to carry the planter over seasons which are adverse to tobacco.

Air-cured and sun-cured tobacco.—The development of these types are indicated by the following export figures:

	lb.
1930	38,329
1931	147,455
1932	166,443
1933	824,396
1934	866,713

The varieties 'Western' and 'Greenwood' are mainly grown, as well as a certain amount of Burley. Suitable areas are more restricted owing to the peculiar climatic conditions necessary for the curing process when the leaf is very subject to injury by rain. The soil should be of similar type to that on which fire-cured tobacco is grown.

Acknowledgements

The figures given in the article are taken from the Annual Reports of the Department of Agriculture, Nyasaland Protectorate, and from the Reports on the External Trade of the Protectorate. Thanks are expressed to the Director of Agriculture for checking the figures relating to dark fired tobacco. The historical references have been acknowledged in the context.

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ERRATA

Vol. III, July 1935, p. 278, line 11 from top, *in lieu of* Dolba Grange *read* Dolga Grange; p. 284, line 21 from top, *in lieu of* 0·75 *read* 0·73; p. 288, line 19 from top, *in lieu of* sown *read* sowing-date.

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